Alleyways and the Perception of Criminal Risk: Exploring Momentary and Context-Specific Perceptions of Criminal Risk Using Virtual Reality

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I confirm that no portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or institute of learning and that this thesis is the result of my independent work, except where otherwise stated. Where relevant, other sources and references have been duly acknowledged.

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Abstract

The overarching aim of this thesis is to advance our understanding into the momentary perceptions of criminal risk and to discern the interplay of contextual factors, for example, visual environmental cues, on this perception. To this end, this thesis investigates the intricate relationship between the environment and the perception of criminal risk, leveraging virtual reality (VR) technology to explore momentary and context-specific perceptions of criminal risk. By employing a gaze-based virtual reality methodology and a follow-up questionnaire survey, this research addresses theoretical and methodological gaps in the understanding of perceptions of criminal risk. Drawing on data, theory, and methodology triangulation, the findings highlight the nuanced interplay between environmental design, incivilities, and the subjective assessment of criminal risk. The study emphasises the dynamic nature of criminal risk perceptions and underscores the significance of environmental cues in shaping individuals' perceptions of criminal risk within alleyways. By illuminating the complex dynamics of risk perceptions in alleyways, this research contributes to developing targeted interventions and inclusive urban planning strategies to foster safer and more accessible urban environments.

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Chapter 1

Introduction

The relationship between environment and the perception of criminal risk has been a focal point of interdisciplinary research, with implications for urban planning, criminology, and psychology. The perception of criminal risk is not a static phenomenon but is shaped momentarily and contextually as and when people navigate urban spaces. Alleyways, being a significant part of the urban and often characterised by narrow passageways and obscured sightlines, have long been associated with heightened perceptions of criminal risk. Despite their historical significance in shaping urban landscapes, alleyways remain underexplored in the context of the perception of criminal risk (Jiang et al., 2018).

Whilst existing studies have provided valuable insights into the general association between the environment and perceived criminal risk, there remains a notable gap in understanding the momentary and context-specific nature of people's perceptions of criminal risk when they navigate these urban spaces. The rapid advancement of technology has opened up new avenues for understanding the intricate dynamics underlying people's perceptions of criminal risk in urban spaces. In recent years, the emergence of Virtual Reality (VR) technology has provided researchers with a powerful tool to simulate realistic and immersive environments, enabling them to examine how people perceive different contexts and respond to different cues that are present in these contexts. By leveraging the capabilities of VR, it is possible to recreate complex real-world scenarios and manipulate environmental cues to explore the nuanced interplay between these cues and the perception of criminal risk. VR offers a unique opportunity to study momentary and context-specific perceptions of criminal risk in controlled yet ecologically valid settings. This motivates the overarching aim of this thesis: to advance our understanding into the momentary perceptions of criminal risk and to discern the interplay of contextual factors, for example, visual environmental cues, on this perception.

1.1 Research questions and objectives

In pursuit of this aim, three key themes are identified: the association between environment and the perception of criminal risk, gaze and the perception of criminal risk, and efficacy of VR as a data collection technique.

Considering these research themes, and the overarching aim of the thesis, the following research questions and objectives are posed:

Research questions:

1. In what way do the design and usage of alleyways impact women's perception of criminal risk?

2. Can virtual reality (simulation) uncover women's momentary and context-specific perceptions of criminal risk?

Research objectives:

1. To establish a conceptual framework capable of informing the design and assessment of an investigation of the momentary and context-specific perceptions of criminal risk in alleyways.

2. To develop a novel approach to obtain momentary and context-specific perceptions of criminal risk.

3. To critically evaluate the efficacy of VR as a tool to explore women's perceptions of criminal risk.

The first objective is to construct a robust conceptual framework capable of informing the design and assessment of an investigation of the momentary and context-specific perceptions of criminal risk in alleyways. This foundational objective serves as the bedrock upon which the entire study is built, as it shapes the approach to designing VR scenarios and evaluating participant responses. In realising this objective, an extensive review of literature spanning disciplines such as criminology and urban design is conducted. This conceptual framework will not only guide the design of immersive VR scenarios but also inform the assessment of participant responses within these virtual alleyway environments.

The second objective involves the development of innovative methodologies to capture momentary and context-specific perceptions of criminal risk, which is a task that traditional research methods such as surveys struggle to accomplish effectively. Central to this objective is the utilisation of VR technology as a tool for creating immersive simulations that mirror real-world alleyway settings.

The third objective centres on critically evaluating the efficacy of VR as a tool for exploring women's perceptions of criminal risk. Whilst VR holds promise for simulating complex environments and experiences, its utility in studying social phenomena such as perceptions of criminal risk requires scrutiny. To address this objective, this study conducts methodological assessments to evaluate the design and implementation of the VR study. Through a comparative analysis of VR results against survey results, this study also allows us to gauge the validity and reliability of VR-generated data. Through these rigorous evaluations, this thesis aims to contribute valuable insights into the strengths and limitations of VR technology in studying perceptions of criminal risk.

Thus, this empirical study attempts to explore the momentary and context-specific perceptions of criminal risk in alleyways via a novel methodological and theoretical triangulation.

1.2 Structure of the thesis

The thesis comprises seven chapters, each serving as a crucial building block in exploring women's perceptions of criminal risk in alleyways through the lens of VR technology.

1.2.1 Chapter 2 – Theoretical framework

This chapter offers an in-depth review of the existing body of literature relevant to the study, exploring theoretical frameworks in criminology and urban design. It synthesises previous studies on the perception of criminal risk in urban settings and examines the role of environmental design and incivilities in shaping criminal risk perceptions. This chapter lays the theoretical foundation for the empirical investigation conducted in the subsequent chapters.

1.2.2 Chapter 3 – Methodological framework

In this chapter, the research methodology employed in the study is described in detail. It explains the specific methods and techniques used in the design and implementation of the VR simulation, including the development of the virtual alleyway environments and the selection of participants. The chapter also discusses the data collection methods and ethical considerations.

1.2.3 Chapter 4 – Development of a gaze-based virtual reality simulation of alleyways

Chapter 4 provides an elaborate description of the development of gaze-based VR simulation presented in Chapter 3. In doing so, it emphasises that the perception of criminal risk, environmental design, and incivilities, whilst interconnected, should be regarded as theoretically distinct phenomena. Therefore, this chapter devises a novel VR methodology centred on gaze behaviour, complemented by a follow-up questionnaire survey. This approach aims to address the theoretical and methodological limitations recognised in Chapters 2 and 3, underlining its novelty through the triangulation of data, theories, and methods.

1.2.4 Chapter 5 – Environment and the perception of criminal risk

Chapter 5 presents the findings generated from the VR experiment and the follow-up survey. The chapter begins by presenting the empirical findings and survey findings. The data description focuses on the association between environmental design, incivilities, and the perception of criminal risk. The chapter then presents the momentary and context-specific nature of the perception of criminal risk to advance existing literature by examining the relative significance of environmental cues. It also explains the importance of demographic characteristics such as age, gender, ethnic origin, religion, socio-economic status, and previous victimisation experiences when people calculate criminal risk.

1.2.5 Chapter 6 – Gaze as a measure of the perception of criminal risk and the efficacy of virtual reality

Chapter 6 presents a detailed comparison between the empirical findings and survey findings for triangulation. In doing so, this chapter examines the potential synergies between the use of gaze as a measure of the perception of criminal risk. This chapter also indicates that the significance of these environmental cues varies contextually and momentarily, and the gaze-based VR simulation was useful in uncovering these momentary and context-specific variations of the perceptions of criminal risk. Then, it assesses the effectiveness of VR as a data collection technique, emphasising the level of immersion and realism, usability, and user comfort, thereby further extending the survey tool to capture participants' experiences concerning the VR study.

1.2.6 Chapter 7 – Conclusion

The concluding chapter provides a comprehensive summary of the key findings of each chapter and contributions of the thesis, emphasising their significance within the broader context of the field. It also reflects on the implications of the research for future studies, offering suggestions for further exploration and advancement in the study of environment and the perceptions of criminal risk. The chapter concludes with a call for continued research and implementation of evidence-based strategies to promote safer and more inclusive urban environments.

Chapter 2

Theoretical framework

2.1 Introduction

Perceptions of criminal risk have been a critical area of study within criminology, with research revealing the intricate interplay between psychological, social, and environmental factors influencing an individual's perception of criminal risk within different contexts (Hale, 1996). Alleyways, often characterised by dim lighting, confined spaces, and limited visibility, have long been associated with heightened concerns for criminal activities (Garofalo, 1981). The perception of criminal risk within these urban corridors has garnered significant attention from both scholars and urban planners seeking to understand the complex interplay between physical environments and human cognition (Ferraro, 1995). Perceptions of criminal risk are not static but rather fluctuate based on various contextual cues and individual experiences, making them dynamic and multifaceted (Kuo and Sullivan, 2001). These perceptions often guide decision-making processes, affecting individuals' choices and behaviours in specific environments. Understanding the intricacies of these perceptions is crucial for developing effective crime prevention and intervention strategies and shaping urban landscapes that foster feelings of safety and security (Hale, 1996; Cozens et al., 2005). Within the realm of criminology, the study of situational crime prevention emphasises the significance of understanding the dynamic interplay between individuals and their environments, particularly as it pertains to the perception of risk.

Traditionally, research on the perception of criminal risk has largely relied on self-report measures and static environmental simulations, limiting the understanding of how momentary and context-specific factors influence such perceptions (Hale, 1996; Farrall et al., 1997; Solymosi et al., 2015; Chataway and Mellberg, 2021). Existing literature has underscored the limitations of traditional research methods in capturing the complexity of individuals' perceptions of criminal risk in real-time and context-specific settings. Existing studies have also highlighted the importance of integrating dynamic environmental factors and temporal fluctuation in studies on perceptions of criminal risk (Farrall et al., 1997; Solymosi et al., 2015; Bannister et al., 2017; Neale et al., 2017; Engström and Kronkvist, 2018; Kim and Kang, 2018; Solymosi et al., 2021). Therefore, a nuanced understanding of the momentary and context-specific nature of the perceptions of criminal risk is imperative for devising targeted and efficient crime prevention interventions.

Building upon this theoretical foundation, this chapter seeks to synthesise and critically analyse the existing scholarship on the perception of criminal risk, focusing on its association with the environment. By examining the limitations and gaps in current research, this chapter aims to provide a comprehensive framework for the proposed study, emphasising the significance of momentary and context-specific factors in shaping individuals' perceptions of criminal risk within dynamic environments. The chapter is structured in the following fashion: Section 2.2 introduces the definitions of the perception of criminal risk in response to the existing literature. Section 2.3 presents relevant theories and theoretical models, focusing on the association between environmental design, incivilities, other psychosocial factors, and the perception of criminal risk. Section 2.4 then explains the alleyways as an important component of the urban setting, and its association with perceptions of criminal risk. Section 2.5 then presents the existing approaches to measuring the perception of criminal risk, speaking to their strengths and limitations. Finally, section 2.6 summarises the gaps in the existing literature, emphasising the motivation to consider new approaches for measuring the perception of criminal risk.

2.2 Defining the perception of criminal risk

The fear of crime literature encompasses a broad range of theoretical perspectives and empirical investigations aimed at understanding the environmental, psychological, social, and cultural aspects of individuals' fears related to criminal victimisation (Ferraro, 1995). Whilst the fear of crime lacks a universally agreed definition (Warr, 2000; Lee, 2001), different definitions and conceptualisations of the perception of criminal risk have been proposed, reflecting the multifaceted nature of this construct within the fear of crime literature. Fear of crime can be understood as an emotional response and as a calculation of risk. Scholars have extensively explored the fear of crime as an emotional response, highlighting its psychological dimensions and individual variations. Ferraro and LaGrange (1987) conceptualise fear of crime as encompassing feelings of vulnerability and apprehension, influenced by personal experiences, demographics, and perceptions of neighbourhood safety. Additionally, media representations of crime events contribute to amplifying fear levels (Jackson, 2009). Conversely, fear of crime as a calculation of risk involves cognitive assessments of potential threats and the likelihood of victimisation. Hale (1996) suggests that fear of crime can also be understood as a rational response to perceived risks, shaped by factors such as crime rates, prior victimisation, and social context. Thus, the fear of crime is a construct that comprises a set of emotional, cognitive, and behavioural attributes.

Owing to the divergent meanings of fear of crime in the literature and the danger of losing any specificity whatsoever, scholars (Garofalo, 1981; Ferraro, 1995; Rader, 2004) have attempted to refine the interpretation of fear of crime by narrowing the meaning. For example, Hale (1996) and Farrall et al. (2007) specified fear of crime as the fear of becoming a victim of crime rather than the actual likelihood of becoming a victim. Ferraro (1995) characterises the fear of crime as an emotional reaction expressed in the form of 'dread' of being targeted by crime or anxiety towards crime in general or towards associated symbols. Whilst it is also argued that the fear of crime differs significantly from only cognitive assessments of danger i.e., the perception of risk of personal victimisation or the perception of criminal risk (Ferraro, 1995), it would also be difficult to differentiate fear from sadness, anger, or despair (Warr, 2000; Lee, 2001).

Consequently, it can be argued that there is an inconsistency in these definitions associated with the fear of crime which may stem from the failure to recognise and differentiate between the emotional, cognitive and behavioural components of fear of crime (Warr, 2000; Clark, 2003). To address these concerns, past studies suggested having two separate scales of questions, one that captures the personal emotional experience and the other that captures personal judgment or calculation of risk (Ferraro and Grange, 1987). One crucial difference often overlooked in measuring and understanding the fear of crime is between a general feeling of fear which is termed expressive fear and a direct experience of fear which is defined as experiential fear (Jackson, 2004; Farrall et al., 2009). Jackson (2004) describes experiential fear as an in-the-moment and direct experience of an individual when perceiving a potential danger or threat. This form of fear is immediate and focuses on actual events or moments of fear and is tied to specific situational or contextual cues. In this case, the fear of crime is seen as something more tangible, for example, a person calculating criminal risk in their immediate environment. Expressive fear, on the other hand, is defined as the general beliefs or concerns about becoming a victim of crime (Jackson, 2004). In broader terms, splitting fear into expressive and experiential categories reflects the idea of fear as either a trait or a state i.e. a temporary feeling (Gabriel and Greve, 2003). Fear as a trait, could be seen as a consistent inner feeling, or as an individual disposition to feel scared in different situations. Stated simply, if someone is generally more anxious about being a victim of crime, they are also more likely to experience specific moments of fear. As Gabriel and Greve (2003) point out, these two aspects of fear of crime are likely to be interrelated. Nonetheless, it is imperative to treat these states and traits as separate concepts as focusing on more specific instances of fear could uncover recurring patterns in these experiences, indicating objectively identifiable circumstances that policy and design interventions could address. Yet, these experiences are seldom investigated, particularly with methodologies capable of capturing the perception of criminal risk as a momentary phenomenon.

Ferraro (1995) argued that perception of criminal risk involves a cognitive understanding of a potentially hazardous situation or environmental cues that generate fear reactions. This evaluation relies on the assimilation of information and environmental cues signalling the likelihood of imminent harm. Similarly, Mesch (2000) defined the perception of criminal risk as a judgement of risk and assessment of safety in an environment. In contrast, the fear of crime represents an emotional reaction of dread, or anxiety to crime, or cues associated with it (Ferraro, 1995). Thus, fear encompasses an emotional, and sometimes physiological, response to perceived danger, which is fundamentally distinct from the experience of perception of criminal risk. In summary, the notion that fear of crime, as an emotional reaction to crime, differs from cognitive assessments, as exemplified by the perception of criminal risk, has received widespread support (Ferguson and Mindel, 2007; Rader et al., 2007). However, existing studies also indicate that both these concepts should be included in investigations to comprehensively understand the fear of crime phenomenon (Warr, 2000; Rader, 2004).

Therefore, to minimise confusion and maintain consistency, this thesis looks at the perception of criminal risk in understanding the fear of crime. It also refers to the perception of criminal risk as an individual's assessment of the likelihood of becoming a victim of a crime and considers the perception of criminal risk as a crucial concept that plays a significant role in shaping people's fear of crime and their responses to it. This perception is shaped by emotional, cognitive, and behavioural attributes, environmental cues, individual characteristics such as age and gender, and media representations of crime, leading to varying levels of perception of criminal risk as and when people navigate urban spaces.

2.3 Perception of criminal risk and its correlates

Existing studies highlight the significance of understanding the psychological, socio-cultural, and environmental determinants of individuals' perceptions of criminal risk. By reviewing the various dimensions of the perception of criminal risk and its correlates, this section seeks to delve into the multifaceted nature of the perception of criminal risk, exploring its various correlates and the underlying factors that contribute to its formation.

2.3.1 The demographics and victimisation model

Existing studies have constructed several conceptual frameworks to investigate the cause of the perception of criminal risk. Notable among these frameworks are the demographics and victimisation model, and the crime or disorder model (Britto, 2013; Zhao et al., 2015). The demographics and victimisation model specifically examines how demographic elements and prior experiences of victimisation contribute to increased levels of the perception of criminal risk. These elements can include but are not limited to gender, age, and socioeconomic status. The model also helps to explain why certain groups may have an increased level of perception of criminal risk compared to others. Moreover, they highlight the importance of demographic and environmental characteristics in people's calculation of the potential risk of criminal victimisation.

Gender is widely recognised as a crucial demographic element in explaining the perception of criminal risk (Ditton and Farrall, 2017; Chataway and Hart, 2019). In quantitative fear of crime studies, gender is commonly treated as a mere control variable, neglecting the potential insights that exploring gender could offer to our understanding of the perception of criminal risk. Franklin and Franklin (2009) argue that the studies around the perception of criminal risk are primarily male-centred and advocate for the significance of feminist research in this domain. Thus, several studies have sought to investigate the reasons behind the persistently higher levels of perception of criminal risk among women, particularly considering victimisation surveys and official crime statistics indicating their lower likelihood of being victimised. According to Hale (1996), the official statistics may probably underestimate the victimisation of women, and victim surveys may not fully capture the depth and breadth of victimisation. This has been further explained by Stanko (1995), who argued that women could have an increased level of perception of criminal risk due to the prevalence of hidden violence against them, for example, domestic violence, sexual harassment and assault, threats of violence, which often go unreported in official statistics or victim surveys. In the fear of crime literature, this is referred to as the shadow of sexual assault hypothesis (Ferraro, 1996). One of the most consistent findings in existing studies around the gendered perception of criminal risk is that women exhibit a greater perception of criminal risk and that the association between their perception of criminal risk and the environment differs for women and men. Johansson and Haandrikman (2023) endorse the notion that general perception of criminal risk theories are better adapted to men than women. Their study also suggests that women's reasons for experiencing a greater perception of criminal risk are not necessarily rooted in the perceived risk of victimisation from what is perceived as criminal activity in one's neighbourhood (Koskela and Pain, 2000), but rather in disorder stemming from human behaviour (Johansson and Haandrikman, 2023). In their study, disorder is referred to as visible signs of decay, neglect, or social disorder, such as vandalism, graffiti, or loitering. These manifestations of disorder can create an environment that fosters fear and unease among residents, influencing their perceptions of criminal risk. For example, women may perceive disorder differently than men due to societal norms and expectations regarding safety and vulnerability. They may be more sensitive to signs of disorder as potential indicators of danger, leading to heightened fear levels (Johansson and Haandrikman, 2023).

Secondly, within the current body of research, age is considered a pivotal factor influencing individuals' perceptions of criminal risk. Extensive research has shed light on how this perception of risk impacts the overall quality of life for the elderly. The prevailing consensus suggests that as people age, their perception of criminal risk tends to intensify. However, studies that delve into the intricate nature of this perception and utilise diverse survey instruments, reveal that the heightened perception of risk among the elderly is constrained to specific dimensions and appears less contradictory than earlier research had indicated (Köber et al., 2022). Generally, older adults do not harbour a more heightened perception of criminal risk compared to younger individuals. Nonetheless, they tend to feel less safe when navigating urban spaces and exhibit more precautionary behaviours, such as avoiding certain locations or refraining from outdoor activities during night-time (LaGrange and Ferraro, 1989; Greve, 1998; Kappes et al., 2013). On the other hand, several studies have uncovered young women, in particular, experience greater levels of perceived criminal risk compared to middle-aged and older groups (Cobbina et al., 2008; Hummelsheim et al., 2011; Koeber and Oberwittler, 2019). Thus, contrary to the perception of criminal risk of older adults, adolescents and young adults are confronted with the highest risk of violent victimisation in real-world environments, thereby making their perceptions of criminal risk seem less paradoxical.

In addition to gender and age, social inequalities have been considered in developing an understanding of people's perception of criminal risk. Both individual-level

(Roman and Chalfin, 2008) and macro-level investigations (Singer et al., 2019) suggest that the perception of criminal risk is influenced by various social and economic attributes and disparities. One of the common findings of these studies is that various indicators of social disparities or social inequalities are related to the expression of perceived criminal risk. Within the spectrum of social inequalities impacting people's perception of criminal risk, socioeconomic status holds particular significance and has frequently served as a proxy for social inequalities (Hernández et al., 2020). Whilst most studies suggest that individuals with a higher socioeconomic status tend to experience a greater level of perceived criminal risk (Pearson and Breetzke, 2014), some studies have reported an inverse relationship (Sookram et al., 2011). From a different perspective, findings of some macro-level studies question the assumption that the perception of criminal risk is exclusively a crime-related phenomenon, rather is connected to daily social processes present in unequal societies and expressed through different forms of anxieties and fears (Hummelsheim et al., 2011; Visser et al., 2013).

Furthermore, the perspective of victimisation is rooted in the idea that the perceived criminal risk in a community is influenced by the level of criminal activity or by hearing about such activities, either through conversations or from the media (Hale, 1996; Jackson, 2005). Therefore, people's prior experience with a crime can contribute to a heightened level of perceived criminal risk. These experiences can be direct (primary or personal victimisation), such as being a victim of a crime themselves (Hale et al., 1994; Tseloni and Zarafonitou, 2008), or indirect (secondary victimisation), like knowing individuals who have been a victim (Lee et al., 2020; Mellberg et al., 2024). These experiences are captured and measured primarily by asking people about their prior experiences with crime in a specified year. In surveys on fear of crime, secondary victimisation is often captured by assessing individuals' exposure to crime-related information, such as media reports or conversations about crime incidents in their community (Jackson, 2005; Lee et al., 2020). In these surveys, people are asked whether they are familiar with anyone close to them who has fallen victim to specific crimes each year. These questions act as control variables for the actual occurrence of crime in their neighbourhood. Moreover, knowing about the victimisation of a crime by others enables the individual to compare themselves and the victim, which can reinforce their sense of vulnerability and the perception of criminal risk (Jackson and Gouseti, 2015). Jackson and Gouseti (2015) suggest that individuals can perceive crime as an issue or a range of occurrences that may vary in relevance across four dimensions: time (when it could occur), space (where it could occur), social distance (to whom it could occur), and hypotheticality (whether it could occur). Therefore, when researchers prompt participants by asking if they are concerned about becoming a victim of a crime, it prompts them to consider crime not only as a theoretical possibility but also as something that could happen to them in their immediate context that could be close in terms of time, space, social proximity, and likelihood.

2.3.2 Incivilities and the perception of criminal risk

The relationship between incivilities and the perception of criminal risk has been a subject of intense scholarly inquiry, generating a significant body of research that underscores the multifaceted nature of this dynamic interplay. Existing studies have highlighted the concept of incivilities, referring to both social and physical conditions that are considered problematic and potentially threatening. This, in turn, has been linked to a negative influence on the perception of criminal risk (Doran and Burgess, 2012; Andrew, 2015). Whilst signs of physical incivilities include graffiti, litter and rubbish lying around, abandoned buildings and vehicles, broken windows, and vandalism, signs of social incivilities encompass public drunkenness, prostitution, drug trafficking, verbal abuse, the presence of gangs, and panhandling (Perkins and Taylor, 1996; Sampson and Raudenbush, 2004; Sampson, 2009; Lopez, 2016; Chataway and Bourke, 2020). In the social context, the presence of incivilities suggests potential victimisation, while physical signs communicate information about deteriorating social circumstances, thus increasing the perception of criminal risk (Nasar and Fisher, 1993). The difference between the two types is the observed presence of disorderly behaviour and observed occurrence of disorderly behaviour. According to the literature, as discussed in Section 2.3.1, the former tends to have a greater impact on people's perception of criminal risk. On the other hand, urban settings exhibiting signs of disorder, such as decayed and destroyed buildings, litter lying around, abandoned vehicles, and other physical incivilities increase the perception of a loss of civil society.

Furthermore, as these cues are more frequently encountered than actual criminal incidents, they possess a greater capacity to instil fear and increase people's perception of criminal risk. Sampson (2009) argues that it is the perception of disorder rather than disorder itself that holds the utmost significance. Additionally, the extent of disorder is contingent upon the specific social context in which it occurs. Another noteworthy contribution came from Hinkle (2015), who investigated various proxies of perception of criminal risk to test the broken windows theory. The findings suggested that heightened levels of perceived social and physical disorder amplify fear and perceptions of criminal risk. However, interestingly, when accounting for emotional fear, the results indicated that while perceived social disorder intensifies fear, perceptions of physical disorder have no effect. Consequently, the study implies that these perceptions might be linked to the view that there are dangerous people in the area, rather than the physical decay itself. All in all, existing literature strongly underscores the significant relationship between incivilities, be it physical or social, and the perception of criminal risk.

2.3.3 Environmental design and the perception of criminal risk

Extending beyond social and physical incivilities, the multifaceted relationship between the design of the environment and people's perception of criminal risk is also a crucial area of enquiry not only in contemporary urban studies but also in the fields of environmental psychology and criminology. Appleton (1975), in his 'Prospect and Refuge' theory, stressed the importance of environmental design to enhance the sense of safety in urban spaces. The prospect element within environmental design refers to the provision of open, unobstructed views that offer opportunities for observation and surveillance. Such features enable individuals to perceive and engage with their surroundings, fostering a sense of connection and control within a given space. Open prospect provides potential victims with enough view to know the conditions of the proximate environment, and thus, reduces the level of perceived criminal risk. On the other hand, the refuge component entails the provision of enclosed, sheltered spaces that offer a sense of security and protection, allowing individuals to seek comfort and safety when needed.

Building on the above-explained prospect-refuge theory, Fisher and Nasar (1992) argue that at the same time, an individual's perception of risk is influenced by the degree to which a space affords prospect and refuge, it is also influenced by the degree to which a space allows escape i.e.; either an exit route from a potential threat, or a connection to others who could respond in case of an attack. Prospect and ease of escape may tend to covary because physical boundaries which limit prospect may also cut off possibilities for escape. In some situations, however, they would differ. For example, a long narrow passageway with solid edges, such as an alleyway, may have deep prospect and little refuge, but limited options for escape. This theory has been widely applied in architecture, urban design and environmental psychology since the early 1990s (Dosen and Ostwald, 2013; Cozens and Sun, 2019). Whilst Research derived from this theory has ascertained that prospect is a vital factor in determining preference and has been supported by a substantial body of evidence (Hagerhall, 2000; Fischer and Shrout, 2006; Cozens and Sun, 2019), evidence for refuge remains variable (Fischer and Shrout, 2006).

Moreover, the basis of prospect-refuge theory has informed the development of design principles aimed at optimising the interplay between visual openness and enclosure in urban spaces, ensuring the creation of spaces that reduce the level of perceived risk, thus, supporting an individual's psychological well-being. This speaks to a strong relationship between the prospect-refuge theory and the urban design concepts – visual permeability and visual entrapment (also known as visual enclosure). The permeability theory explains that safety and danger can be considered parallel to the perception of open and enclosed spaces (Baran et al., 2018). Visual permeability of an urban space refers to the degree to which a person can observe the characteristics of an environment without any obstacles. It is also sometimes interpreted as the visibility, openness, and spaciousness of a place (Chiang et al., 2014; Baran et al., 2018). Existing studies in the field of urban design also suggest that possible criminal risks and threats are related to increasing enclosure (Baran et al., 2018). Evidently, both visual and physical permeability seem to have a significant effect on perceived criminal risk (Lis et al., 2019; Sezavar et al., 2023). However, existing studies around the perception of criminal risk suggest that visual cues, including incivilities and environmental design play a more influential role in people's perception of criminal risk as opposed to demographic and social factors (Nasar and Fisher, 1993; Boomsma and Steg, 2012; Jackson and Gouseti, 2012; Crosby and Hermens, 2018).

Further extending beyond social and physical incivilities, and focusing on visual cues, the presence and quality of streetlighting play a critical role in shaping people's perception of criminal risk. Streetlighting is an issue associated with the perception of criminal risk, yet independent of other theoretical explanations that were discussed above. It speaks to factors that enable or impede people's ability to read other visual environmental cues. A study by Nasar and Jones (1997) investigated the relationship between streetlighting and the perception of safety in urban environments. It was found that well-lit streets were associated with a reduced perception of criminal risk and increased feelings of safety among residents. In contrast, poorly lit areas were more likely to evoke concerns about potential criminal risks and foster a heightened sense of vulnerability. Further, Hanyu (2000) used two sets of photographs of the same places out of which, one was taken during the day time, and the other, after dark. Participants were asked to rate these photographs based on how fearful they were when they were shown the photographs. Results suggest that people can perceive the same urban environment differently at different times of the day as they tend to be more fearful after dark. Hanyu (2000) also argues that at night, the fear of crime can be reduced by uniformly locating bright street lighting. It was also found from similar studies that streetlighting offers higher reassurance amongst pedestrians after dark, which in turn implies a lower level of perceived criminal risk (Guedes and Cardoso, 2013; Fotios et al., 2015a; Rahm et al., 2021).

Moreover, it is important to understand how the amount of light affects the perception of safety at night. To address this problem, Boyce et al. (2000) carried out a study using field surveys of 24 car parks in urban and suburban areas. It was observed that as illuminance increased, the difference between ratings of perceived risk at day and night tended to decrease. Since the fear of crime is higher after dark, researchers argue that by reducing darkness, the fear of crime would also be reduced. As is evident from the literature the relationship between lighting and perceived safety at night is intuitively strong, its workings in terms of theoretical and empirical aspects are largely unknown. With the advancement in technology, it is possible to introduce intelligent dynamic street lighting which continuously adapts to the presence and behaviour of users, and which can light the street only when and where it is needed. With this innovation, Haans and de Kort (2012) focused not only on how much lighting pedestrians need to feel safe but also on which parts of the street should be lit. In two experiments, they investigated the effect of different light distributions on perceived safety and explored mediation by people's appraisal of three safety-related cues suggested in the literature and mentioned in the above section: prospect (having an overview), escape (perceived escape possibilities), and refuge or concealment (perceived hiding places for offenders). Both experiments, one with stationary and one with walking participants, demonstrated that people prefer having light in their own immediate surroundings rather than on the road that lies ahead. This could be explained, partially, by changes in prospect, escape, and concealment. A more recent study by Son et al. (2023) uses VR to analyse the relationship between night-time illuminance and the fear of crime in four narrow streets in Seoul. At each location, the levels of illuminance were measured during specific time intervals using a 360-degree camera to capture natural scenes and a questionnaire survey based on recorded VR videos was administered to 101 young adults. The findings of their study indicated that all measured illuminance variables were negatively correlated with the fear of crime. Their VR experiments reaffirmed that not only horizontal average and vertical minimum illumination but also uniformity can contribute to reducing the fear of crime.

Existing studies around the perception of criminal risk emphasise that individual perceptions of risk are situated within their understanding of the social and physical make-up of the environment that they are in (Jackson, 2004). This points further to the role of the environmental backcloth in studying the perception of criminal risk.

Further, this relevance of the environment to the perception of criminal risk indicates that the environmental design and alterations to it can be a robust urban planning tool to control the levels of the perceived criminal risk experienced by individuals. Notwithstanding the other contributing factors, visual cues associated with environmental design and incivilities play a significant role in reducing the levels of perceived criminal risk and enhancing people's emotional health. However, the theoretical models that employed these incivilities and design concepts are also highly relevant in the moments that people use the environment, which speaks to the context-specific and momentary nature of how people perceive these visual cues in calculating criminal risk. Adding to this, it is also important to note, that whilst the theoretical explanations in Sections 2.3.2 and 2.3.3 highlight the significance of these incivilities and environmental design, including streetlighting in people calculating criminal risk, these need further disentangling, focusing on their importance and relation to one another.

2.4 Alleyways and the perception of criminal risk

Alleyways, with their often confined and enclosed nature, can evoke a heightened perception of criminal risk, impacting how individuals navigate these urban spaces, despite being a common urban space (Jiang et al., 2018). In the context where environmental design is grounded in criminology theories such as prospect-refuge that have been empirically tested, it becomes evident that the design and layout of alleyways significantly influence people's perception of criminal risk.

One prominent factor contributing to the negative perception of alleyways is their physical design, which is the design of the environment. With limited visibility (also known as visual permeability), poor lighting, and confined spaces, alleyways can create a sense of anonymity and isolation, fostering an environment conducive to illicit activities. Their secluded nature often makes them attractive to individuals seeking to engage in illegal behaviour away from the scrutiny of law enforcement and the public. Consequently, this association between alleyways and the perception of criminal risk can perpetuate a cycle of actual and perceived criminal risk, leading to the stigmatisation of these spaces.

On the other hand, it is essential to consider the socioeconomic context within which these alleyways exist. Often located in poor neighbourhoods, alleyways can serve as shortcuts or vital pedestrian passages. Neglecting these spaces or perceiving them solely through the lens of perceived criminal risk may overlook the significance of alleyways as integral components of urban infrastructure.

Despite the lower occurrence of actual crimes in alleys, they are often perceived as unsafe, leading individuals to avoid or modify their behaviour in such spaces (Jiang et al., 2018). Herzog and Flynn-Smith (2001), in their study, examined the association between perceived danger and various characteristics of urban alleyways, which include upkeep of alleyways, curvature, width, and length. Participants were presented with photographs of diverse alley types and were questioned about their feelings towards each characteristic, which reveal that narrower alleys are more commonly associated with a heightened sense of danger, while well-maintained alleyways with surveillance were perceived safe. Conversely, poorly maintained alleyways increased the perception of criminal risk. These findings align with the 'Broken Windows' theory (Wilson and Kelling, 1982). Whilst empirical studies into urban alleys are infrequent within the realms of environmental design and criminology, existing studies in similar urban settings suggest that environmental interventions could improve the perceptions of criminal risk attached to these places (Branas et al., 2018).

Furthermore, existing studies around the perception of criminal risk argue that people have an innate ability to understand a place and estimate criminal risk through a quick visual perception (Innes, 2004; O'Brien and Wilson, 2011). Clues in the visual environment help people make this judgment. This echoes the possibility of perceived criminal risk being context-specific. However, to understand the dynamic nature of the perception of criminal risk, measurement must be considered.

2.5 Empirical measurement of the perception of criminal risk

Existing studies that explore the perception of criminal risk predominantly involve surveying a large population within a specific area of interest. Whilst this may identify general findings for the area, it would fall short in pinpointing individual determinants. Further, several studies reveal notable impacts of the perceived criminal risk on people's activities (Burke et al., 2009; Lorenc et al., 2013b). Additionally, Chun and Lim (2015) found that responses related to the perception of criminal risk varied based on the wording of the surveys for each population, thereby compromising the validity of comparisons. Moreover, several studies argue that differentiating emotional responses from the perceived risk of crime is crucial for understanding this (Ferraro, 1995; Asencio et al., 2014).

Some surveys employed to capture people's perception of risk are retrospective in nature, which ask people to recall their activities, potentially leading to over-generalised answers and skewed results (Gray and Jackson, 2008). This approach might also overlook contextual and momentary variations in the perception of criminal risk. Consequently, such data fail to facilitate the examination of dynamic fluctuations and do not adequately account for specific geographical contexts, thus lacking sensitivity to both time and space. As a result, this limitation can impede the advancement of theories concerning the influence of environmental cues on the perception of criminal risk. Additionally, when assessing the perception of criminal risk through retrospective cross-sectional questionnaires, individuals may resort to using heuristics to address a challenging question, substituting it with an easier one (e.g., expressing general thoughts about the perception of crime instead of evaluating personal concerns while engaging in daily activities) (Kahneman, 2012). There also remain various other dynamic personal factors that warrant consideration. For instance, the concept of psychological distance, where individuals perceive a higher likelihood of becoming crime victims when they feel closer to a crime event spatially, temporally, and socially impacts their perception of criminal risk (Trope and Liberman, 2010; Jackson and Gouseti, 2015). Rather than relying on a global composite measure, understanding the perception of criminal risk as an event that is specific to context and time would offer a more dynamic portrayal of this phenomenon, allowing us to advance theories in this field.

For a more precise understanding of the perception of criminal risk as an event within a specific setting, the 2003-2004 phase of the British Crime Survey (now named the

Crime Survey of England and Wales) introduced questions about the frequency and intensity of this perception (Farrall and Gadd, 2004). This shift towards assessing the perception of criminal risk as an event experienced in daily life, as opposed to a fundamental attitude or anxiety, represents a change in focus. Consequently, it provides a more accurate depiction of what individuals experience in their everyday routines. This emphasis situates the perception of criminal risk within the context of people's daily activities and the broader societal and environmental frameworks.

In response, this approach attempts to bring the perception of criminal risk into the domain of urban planning and design. In doing so, it would be possible to determine when and where people experience a heightened perception of criminal risk and understand what environmental cues provoke such perceptions in people, thereby, allowing us to examine the association between the environment and the perception of criminal risk.

Despite the attempts to advance understanding of the association between the environment and the perception of criminal risk through revising the questions to shift the focus as explained above, survey tools remain cross-sectional, which captures people's perception of crime only at one point in time and place, thus, capturing a static response. Further, this does not address the issues around self-reports, respondents' recall, or reluctance to reveal emotions (Warr, 2000). Issues with respondents' recall have always been inherent in quantitative survey research within the social sciences (Bernard et al., 1984), which may be prone to inaccuracies owing to respondents being unable to remember details of events or experiences accurately. Regarding the perception of criminal risk, these recollections of experiences dating back further than approximately two weeks rely more on general beliefs related to the particular event than the specifics of the event itself (Robinson and Clore, 2002).

As explained above, owing to the cross-sectional nature of the surveys, they continue to overlook the context-specific and momentary fluctuations in an individual's perception of criminal risk. As discussed, these encounters probably vary among individuals due to various environmental factors, including the time of day and familiarity with a particular area (Brantingham and Brantingham, 2017). Whilst these improved measures emphasise the importance of understanding the perception of criminal risk as an experience that shifts momentarily, they still struggle to capture its dynamic nature i.e., the idea that perception of criminal risk fluctuates within a short time frame and is dependent on the environmental context. Owing to these shortcomings of traditional methods used to examine the perception of criminal risk, there has been a revived focus on the application of new methods and technologies to improve the measurement of the perception of criminal risk to understand it context-specific and momentary nature and to advance existing theories around the nature of this phenomenon (Noon et al., 2019).

2.6 Gap in the literature and conclusion

The existing literature on measuring the perception of criminal risk reveals a notable gap in understanding the nuances of this complex phenomenon. Whilst numerous studies have attempted to assess the perception of criminal risk through different methodologies, there remains a persistent discrepancy in comprehensively capturing the dynamic nature of this perception.

One key issue pertains to the reliance on traditional cross-sectional surveys, which often provide static snapshots of individuals' experiences at a specific point in time. This approach, while helpful in outlining general trends, tends to overlook the contextual variations and nuances in how people experience and perceive criminal risk on a day-to-day basis. Additionally, the use of self-report measures and subjective accounts can inadvertently lead participants to respond in socially desirable ways, potentially skewing the results and failing to capture the true depth of their perceptions.

Moreover, the abstract nature of some of the questions used in these surveys, focusing on subjective feelings of safety and worry, may not fully encapsulate the intricate dynamics of how individuals navigate and respond to the perceived risks of crime in their environments. The subjective nature of these enquiries often leaves room for interpretation and may not provide a holistic understanding of the multifaceted dimensions of fear of crime.

Furthermore, the current methodologies often lack the ability to account for context-specific and momentary variations in individuals' perceptions of criminal risk. The dynamic nature of this phenomenon, which can fluctuate within short time frames and differ across various micro-environments, remains inadequately captured by existing measurement tools.

In light of these limitations, there is a growing recognition of the need for more refined and comprehensive approaches that can better encapsulate the intricacies of people’s perceptions of criminal risk. Studies are now emphasising the development of more dynamic measures that can account for the complex interplay of contextual, momentary, and individual factors, thereby bridging the gap in the literature and providing a more nuanced understanding of the perception of criminal risk. Such advancements in measurement techniques are crucial for advancing our knowledge of this critical aspect of societal well-being and for informing effective interventions in the realms of urban planning, crime prevention, and community safety.

Overall, the motivation to explore new methodologies for the examination of the perception of criminal risk is grounded in the critical evaluation of the limitations inherent in traditional approaches. Through a comprehensive discussion of these limitations, it becomes evident that traditional methods often fail to account for the dynamic and complex nature of these perceptions. By relying solely on static indicators, traditional approaches may overlook the evolving patterns and cues that influence people’s perceptions of criminal risk. Furthermore, these methods may neglect the intricate interplay of psychological, social, and environmental factors that influence individuals' perceptions of criminal risk, leading to a limited understanding of the subjective dimensions of fear and their relation to one another. Thus, the recognition of these constraints serves as a catalyst for the exploration and implementation of innovative techniques that integrate advanced interdisciplinary research and methods. To this end, the next chapter presents a comprehensive methodology through theoretical and methodological triangulation that as an attempt to advance our understanding into the momentary perceptions of criminal risk and to discern the interplay of contextual factors, for example, visual environmental cues, on this perception.

Chapter 3

Methodological framework

3.1 Introduction

The traditional way to collect data about fear of crime is to use surveys (Ferraro and Grange, 1987; Hale, 1996). These generally are retrospective, cross-sectional questionnaires which ask people at one point in time to recall their activities, thoughts, and behaviour relating to an outcome variable of interest. National surveys such as the Crime Survey for England and Wales (CSEW) in the United Kingdom (Hale, 1996; Hinkle, 2015), ask representative samples about their fear of crime and associate these with various situational variables. Whilst such surveys have many strengths, they also have weaknesses. One such weakness is that the respondents are required to recall their perceptions and activities. This can lead to over-generalised answers and potentially skewed results (Gray et al., 2012). For these reasons, as explained in Chapter 2, Section 2.5, data gathered in this way do not lend themselves to measuring context-specific and momentary perceptions of criminal risk.

In these terms, methodological innovation is required to robustly capture the context-specific and momentary nature of the perception of criminal risk. With this narrative in mind, this chapter presents the comprehensive methodology adopted in this study, focusing on the systematic journey undertaken to achieve the research objectives, thereby addressing the research questions. The chapter is structured in the following fashion: Section 3.2 discusses emerging and novel approaches used to measure people's perception of criminal risk and their strengths and weaknesses. Section 3.3 then discusses the strengths and limitations of virtual reality as a potential data collection technique, focusing on capturing the context-specific and momentary perceptions of criminal risk through gaze data. Section 3.4 then presents the design of virtual reality experimental study, focusing on data and methodological triangulation. Section 3.5 explains the practical and ethical implications of the virtual reality experimental study. Next, Section 3.6 explains the VR laboratory setting and how it was set up for the VR experiment. Finally, Section 3.7 highlights the gaps in emerging and novel approaches and the need for a robust approach to capture context-specific and momentary perceptions of criminal risk.

3.2 Emerging approaches for measuring people's perceptions

As traditional methods of measuring these perceptions have often been limited in their scope and effectiveness, there has been a growing interest in the development and application of emerging approaches for a more nuanced and comprehensive assessment of people's perception of criminal risk. Drawing upon advancements in environmental psychology, criminology, urban studies, and technology, researchers and practitioners have begun to explore innovative methodologies that delve deeper into the intricacies of how individuals perceive and respond to criminal risks. These novel approaches offer a promising avenue for understanding the complexities of perceived criminal risk and its implications for crime prevention strategies and policy formulation. To this end, this section discusses some of the key emerging approaches in the field for measuring the perception of criminal risk, highlighting their strengths and limitations. It also emphasises the potential of these approaches to enhance our understanding of the dynamic nature i.e., the context-specific and momentary nature, of the perception of criminal risk.

With the progression of information and mobile technologies, as well as the emergence of social media and crowdsourcing, there has been a rise in the use of both two-dimensional (2D) and three-dimensional (3D) computer-assisted techniques that attempt to capture people's perceptions. These methods are aimed at studying how individuals perceive specific urban settings. Several of these innovative approaches have been experimented with, such as extracting semantics from locations through the analysis of photo tags on platforms like Flickr (Rattenbury and Naaman, 2009), and predicting crowd emotions and their spatial and temporal distribution through the examination of Twitter data (Resch et al., 2016).

Resch et al. (2016) suggest an urban planning method that prioritises the perspective of citizens and employs tweets to evaluate public perceptions and emotions associated with the city in an interdisciplinary fashion. They extract emotions from tweets based on geographical location, time, and language, assigning specific emotional categories such as happiness, anger, sadness, and fear to each post. Their research introduces the Twitter Emotion Labeller (TwEmLab), which serves as a comprehensive implementation framework for classifying tweets into emotional categories through a multifaceted approach. Their empirical research indicates that emotions can be identified under certain conditions through an integrated approach involving space, time, and language.

Further, Solymosi et al. (2015) created FOCA, an application designed to enhance the accuracy of identifying fear of crime against both space and time using crowdsourced data. Their investigation primarily aimed at recognising unsafe zones within the entire travel environment of individuals. Similarly, MacKerron and Mourato (2013) carried out a study utilising crowdsourced data, where they developed the mobile application Mappiness. Users of this app were prompted to indicate their level of 'happiness' on a continuous sliding scale. They were also required to provide information about who they were with, their location, and their activity. The precise GPS location was automatically recorded as participants responded. While this study offers new insights into the connection between the surroundings and subjective well-being, the potential bias introduced by self-selection of participants may impact the generalisability of the findings.

Understanding people’s perceptions is a key theme in neuroscience concerning eliciting emotions through brain activity. With the progress over the years, a distinct area of research has surfaced with the intention of gleaning insights into the field of urban planning and design through knowledge and techniques derived from neuroscience (Gepshtein and Snider, 2019). In an effort to directly evaluate individuals' neural reactions to a dynamic urban setting during walking, Neale et al. (2017) suggest using electroencephalography (EEG). Specifically, this study focuses on individuals aged 65 years or older, who were recruited to take a 15-minute walk in one of six scenarios, involving urban busy (a commercial street with traffic), urban quiet (a residential street), and urban green (a public park) spaces. During the walks, participants wore a mobile Emotiv EEG headset to capture real-time neural responses to the surroundings. The results yielded emotional parameters such as excitement, frustration, engagement, and meditation, each with a real-time value.

Moreover, Kim and Kang (2018) introduced a protocol for assessing physiological signals alongside existing surveys, allowing for the real-time evaluation of an individual's perception of criminal risk. Their research involved the use of six video clips depicting actual pedestrian environments, including daytime and nighttime views of a commercial street, a residential street, and a natural street. Participants watched these clips while their electroencephalographic (EEG), electrocardiographic (ECG), and galvanic skin response (GSR) signals were recorded and compared. The results indicated that the physiological signals were influenced by the level of awareness an individual had regarding their fear of crime. Additionally, significant distinctions were observed between two participant groups belonging to different age categories. This study highlights the significance of individual characteristics in gauging the perceived criminal risk.

Apart from the aforementioned studies, several other studies have used similar customised mobile applications to collect data concerning perceived safety and perceptions of criminal risk (Solymosi et al., 2015; Birenboim, 2016; Chataway et al., 2017). Additionally, there have been studies that have employed self-developed online platforms to explore crowdsourced data associated with the fear of crime (Candeia et al., 2017; Pánek, 2019). It is noteworthy that all of these studies recorded geographical information, thereby generating spatially explicit data concerning individuals' encounters with the fear of crime, while advocating for a place-centric approach to assessing emotional responses to crime. Consequently, the approaches to formulating questions for measuring the fear of crime ranged from enquiries based on previous survey-based fear of crime research to requesting participants to rank locations (Candeia et al., 2017; Chataway et al., 2017; Solymosi and Bowers, 2018).

Previously mentioned studies that utilise crowdsourced data through custom mobile applications or online participatory mapping platforms can capture specific variations in the fear of crime within certain contexts. According to Birenboim (2016), mobile technologies enable the acquisition of highly precise spatial and temporal data, allowing for the mapping of real-time experiences at the minutest scale possible. This level of precision facilitates accurate correlations between these perceptions and environmental cues, such as physical and social incivilities (Solymosi et al., 2015).

Furthermore, these methods also enhance our comprehension of the role played by various environmental cues and the built environment by collecting specific information on different environmental features. This additional context can provide a deeper understanding of people's perceptions and experiences. Therefore, data acquired through crowdsourcing methodologies can contribute to more effective policy-making regarding the design and modification of urban environments to mitigate feelings of fear.

Despite the significant benefits outlined earlier, these crowdsourcing methods come with limitations on their own. These limitations primarily revolve around sampling, as various studies employing crowdsourced data collection platforms have periodically revisited concerns regarding sampling (Bethlehem and Biffignandi, 2021). They may also be linked to the self-selection bias of participants, resulting in the underrepresentation of the elderly and the overrepresentation of young people. This imbalance occurs because certain groups, such as the elderly, are not reached effectively by these approaches (Chataway et al., 2017). Another issue stemming from this participation inequality is the disparity within the sample, with a small group of participants contributing the majority of the data (Solymosi and Bowers, 2018).

To this end, Chataway et al. (2017) propose the use of sampling techniques such as the Experience Sampling Method (ESM) or Ecological Momentary Assessment (EMA) to reduce the bias stemming from participation inequality and subjective decisions regarding the time and place of report submissions. Moreover, beyond relying solely on crowdsourcing methodologies, some recent studies suggest that combining crowdsourcing techniques with machine learning methods could potentially address issues related to bias. This is because machine learning tools train computational algorithms to replicate patterns captured by human participation in unreported or underreported urban areas (Candeia et al., 2017). However, such machine learning methods with computational modeling can only be applied to urban areas with existing crowdsourced data, thereby limiting their applicability in predicting perceived safety in other areas where such data is unavailable (Harvey et al., 2015).

Crowdsourced data may encounter challenges when it comes to linking individuals' risk perceptions with environmental cues. Consequently, interpreting data collected through crowdsourcing methods can be intricate in terms of identifying specific reasons for certain spaces being more fear provoking than others. This complexity arises from the dynamic and ever-changing nature of variables within real-world settings. Similarly, asking participants to assess or rank images on an online platform may not accurately represent their actual experiences or perceptions, as these judgments can be influenced by other sensory elements like noise, smell, and weather conditions (Harvey et al., 2015).

Overall, traditional survey-based methods have exhibited notable limitations, as they do not provide data on the perception of criminal risk in relation to real-time experiences, thus failing to capture momentary and context-specific perceptions of criminal risk. Purpose-built mobile and web applications aim to address these shortcomings by utilising geo-coded data, but present more drawbacks than advantages. Further, employing app-based crowdsourced approaches could help gather spatial and temporal data concerning the perceptions to some extent.

However, data derived from these methods can be biased in terms of participation, as not everyone has access to such technology. For instance, the elderly population is often excluded when collecting data through crowdsourcing approaches. Although online crowdsourced methods exhibit potential in covering a large spatial scale and sample size, they tend to be less effective in capturing data that accurately represents people's perceptions of criminal risk in areas that are generally avoided for safety reasons. Additionally, they struggle to capture momentary and context-specific perceptions of criminal risk, especially considering the dynamic nature of certain environmental cues, such as social presence (for example, moving people and people hanging out on street corners).

These limitations in both traditional survey-based methods and more recent methodologies call for approaches that can uncover people's momentary and context-specific perceptions of criminal risk, not only at specific points in physical space but also in terms of how these perceptions change as individuals navigate urban spaces, and that can critically assess the effectiveness of these methods and techniques in exploring people's perception of criminal risk. Therefore, along with the aforementioned requirements, it is evident from the literature that there is a need to enhance the reliability and validity of the perception of criminal risk measures. Avenues to address these gaps require an approach through theoretical, methodological, and data triangulation that can probe public perceptions of the environment.

3.3 Gaze behaviour in virtual reality: a potential data collection technique

3.3.1 Virtual Reality: theoretical explanations

The utilisation of VR in research has its roots in the 1960s, with the development of the first Head Mounted Display (HMD) known as 'The Sword of Damocles' by Ivan Sutherland (Wohlgenannt et al., 2020). Subsequent advancements included the 'Large Expanse Extra Perspective (LEEP) system' by Eric Howlett in the 1970s, along with other VR devices such as the 'EyePhone' (an HMD), 'DataGlove,' and 'DataSuit' designed for tracking movements (Sherman and Craig, 2018). However, early VR technology and systems appeared to have limited graphical capabilities and issues related to inducing motion sickness. These setbacks led to the development of the 'CAVE Automatic Virtual Environment' with the aim of achieving higher resolution and reduced system latency (Cruz-Neira et al., 1993). Despite these efforts, the use of 'CAVEs' remained confined to specific professional applications in fields like engineering, military training, and medicine, as they required dedicated rooms and expensive projectors (Muhanna, 2015).

To address the shortcomings of early VR systems, the gaming industry began developing more consumer-oriented and research-focused HMDs such as the 'Oculus Rift,' 'HTC Vive,' and 'PlayStation VR,' incorporating features like headphones for sound, haptic controllers, and various other hardware components, including haptic gloves. These advancements aimed to enhance the sense of presence, interaction, and immersion (Mach et al., 2019). Furthermore, contemporary VR systems such as 'Oculus Quest' and 'HTC Vive Focus,' which are wireless and fully standalone, offer additional advantages, including portability, plug-and-play capabilities, and the freedom to use them anywhere at any time. As a result, modern VR technologies can substitute real-world sensory inputs with synthetic stimuli like 3D visual imagery and spatialised sounds (Wohlgenannt et al., 2020).

Although interpretations of VR can vary across different fields of research and applications, all its definitions share three common properties: presence, interactivity, and immersion (Walsh and Pawlowski, 2002). In the context of VR, presence refers to the sensation of physically being present in a location that is different from one's actual physical environment (Sanchez-Vives and Slater, 2005). Interactivity involves the user's ability to interact with the virtual environment through various actions, such as changing locations, altering the direction of movement, picking up and putting down objects, adjusting walking speed, and other interactions that allow them to modify their viewpoint within the virtual setting. Interactivity is also defined as the extent to which a user can manipulate their virtual environment in real-time (Wohlgenannt et al., 2020). Thus, interactivity can influence presence by enabling a range of movements and actions, allowing users to access new perspectives through head movements.

Understanding of immersion often appears to overlap significantly with the concept of presence. Some researchers view immersion as an objectively measurable property based on technological features such as inclusiveness, the scope of the field of view, the extent of sensory feedback involved, and the quality of the displays (Sanchez-Vives and Slater, 2005; Wohlgenannt et al., 2020). Immersion is also perceived as a subjective involvement by other scholars, which can encompass cognitive immersion, emotional immersion, sensory-motor immersion, and spatial immersion (Nilsson et al., 2016).

However, the aforementioned studies may pique the interest of social scientists and researchers in the humanities, not only for the scientific discoveries they unveil but also for the insights they provide into the formidable capabilities of VR when engaging with participants (Reger et al., 2011). Consequently, in recent years, other research domains, including the social sciences, humanities, and natural sciences, have begun exploring the potential of VR in their respective fields, particularly in the context of human-environment interactions and the elicitation of diverse perspectives on specific environments. The key advantage it offers lies in enabling individuals to delve into experiences that transcend the limitations of the physical world yet feel the same realism. Therefore, VR can serve as a tool for both researchers and their participants to delve into a wide spectrum of social and embodied experiences, within the realistic virtual environment (Jones et al., 2022).

A significant portion of VR research concentrates on its technical performance and industrial applications, underscoring its potential for fostering collaboration. This includes the collaborative development, testing, and implementation of VR projects across various disciplines, while drawing upon theories, practices, and constructs from the broader realms of the social sciences and humanities that could significantly enhance research endeavours. To this end, VR can serve as a valuable tool in the fields of urban planning and design, providing crucial support for informed decision-making processes based on spatial reasoning.

3.3.2 Gaze behaviour: theoretical explanations

Gaze shifts hold significant importance in the realm of human-computer interactions (HCI), as they provide strong indicators of attention, interest, and intention, which can be utilised as contextual cues and inputs (Sidenmark and Gellersen, 2020). In our engagement with the surroundings, gaze shifts occur through a combination of eye, head, and body movements. When individuals shift their gaze, they typically move their eyes within their sockets, rotate their heads in relation to their torsos, and adjust their torsos concerning the environment (Land, 2004). For instance, when someone shifts their focus from a screen in front of them to a second handheld screen, they lower their eyes while tilting their head accordingly. Similarly, when they look upward toward someone standing beside them, they not only move their eyes and head but also turn their torso toward the new point of interest. Additionally, research on reading has demonstrated that the head often moves in coordination with the eyes and that during daily activities, people tend to align their eyes and head when inspecting visual objects in detail (Nakashima and Shioiri, 2014). Moreover, various studies have established a connection between head and eye movements and visual attention (Khan et al., 2009; Doshi and Trivedi, 2012). While this highlights the seamless coordination of the eye and head movement system for effective targeting of gazes, existing gaze studies have not fully accounted for the coordination of eye, head, and torso movements, which naturally facilitate gaze shifts (Sidenmark and Gellersen, 2020).

3.3.3 Application of virtual reality for capturing people's perceptions

Among the various possible applications for virtual environment technologies, simulating architectural and urban spaces is one of the most apparent. VR has the potential to enrich the exergaming experience through immersion and presence, contributing to a sense of absorption, flow, and enjoyment (Staiano et al., 2017). Further, advanced VR technologies of the current generation offer increasingly realistic experiences at reduced costs.

VR is characterised as a digitally constructed portrayal of a natural or artificial environment (Loomis et al., 1999), where real-world cues are substituted with digital ones (Fox et al., 2009). This opens endless possibilities for presentation within the virtual environment (Slater and Sanchez-Vives, 2016). The technological advancements in head-mounted displays that track the user's head position introduce a novel viewing experience by fully shielding the wearer's sensory perceptions from the actual environment (Renaud et al., 2002). Various fields have so far employed VR, ranging from scientific applications and professional training to the entertainment industry (Simon and Greitemeyer, 2019).

Beyond technological maturity and economic feasibility, one of the crucial factors contributing to the success and user acceptance of VR solutions is the overall user experience. The user experience encompasses the user's complete interaction with the device or service, along with the thoughts, emotions, and perceptions that result from this interaction. This process involves the user interacting with the device and their experience, which can be observed or measured (Tullis and Albert, 2013). Several research endeavours have proposed immersive virtual reality as a tool for evaluating the effectiveness of such interventions. However, the perception of individuals within virtual environments still requires validation (Luigi et al., 2015). One aspect of the perceived quality of urban spaces involves understanding the appropriate balance between sound and visual components (Pheasant et al., 2010; Brambilla and Maffei, 2010). Numerous studies have been conducted to identify the factors influencing the perception of urban spaces. Some have evaluated the acoustic-visual conditions in parks and squares (Brambilla et al., 2013) while others have proposed methodologies for characterising urban spaces by assessing their effectiveness in areas with potentially restorative features, such as waterfronts (Luigi et al., 2015). Table 3.1 presents an overview of how VR surpasses traditional survey methods and technologies, primarily in terms of five identified uses or applications of VR.

Table 3.1: Summary of using virtual reality over traditional methods for exploring people's perceptions

Application / Use	**Comparison of features/capabilities/advantages**	
	Traditional methods (Surveys)	**Virtual reality**
Real-time spatial representation	×	✓
Simulation of the physical environment	×	✓
Deliver realistic multi-sensory experiences	×	✓
Three-dimensional (3D)	×	✓
Integration of dynamic features (eg: moving people, men hanging out around street corners)	×	✓

As previously mentioned, VR has found applications in studying people's perceptions, particularly through the creation of simulated environments that replicate real or hypothetical scenarios. Few studies have explored the use of VR in this context, such as Cozens et al. (2003) and Park et al. (2010), who have respectively examined the potential of Quick Time Virtual Reality (QTVR) and VR-based navigation to study the fear of crime. Additionally, Castro-Toledo et al. (2019) have demonstrated the feasibility of utilising 360-degree videos in VR to enhance the representation of real environments for studying perceptions. However, there are ethical and practical challenges associated with capturing authentic 360-degree footage for these studies.

Furthermore, Toet and van Schaik (2012) have emphasised the importance of ecological validity in VR simulations to accurately represent the real environment. They highlight the significance of incorporating dynamic features such as visual, auditory, olfactory, and haptic cues to enhance the realism and immersion of VR experiences. Dynamic audio cues encompass human and animal sounds, while dynamic visual cues can include moving objects and human interaction. Additionally, the integration of olfactory cues such as unpleasant odours in alleys and haptic cues like varying air sensations during walks further enrich the user experience. This comprehensive integration of dynamic elements is vital in effectively eliciting cognitive, emotional, and behavioural responses from individuals within VR simulations. Despite these advancements, there remains a need for further exploration of VR methodologies in studying the perceptions to ensure the validity and reliability of the obtained results.

3.4 Design of virtual reality experimental study

3.4.1 Experimental framework

Whilst VR data and analytics provide insight into how and what people perceive in urban environments and their perceptions toward these environments, such data also relies on many assumptions and needs to be cleaned and prepared, and inferences about what the data reflects must be made and justified. These steps allow for issues to emerge around the validity and reliability of such data to reflect the outcome variable of interest to the researcher. One way to address these issues is to collect information that is needed from people directly and in real-time, as is the case with VR experiments. This section presents an experimental framework (see Figure 3.1) that is designed and developed using Unreal Engine 4, to collect momentary and context-specific perceptions of criminal risk using VR.

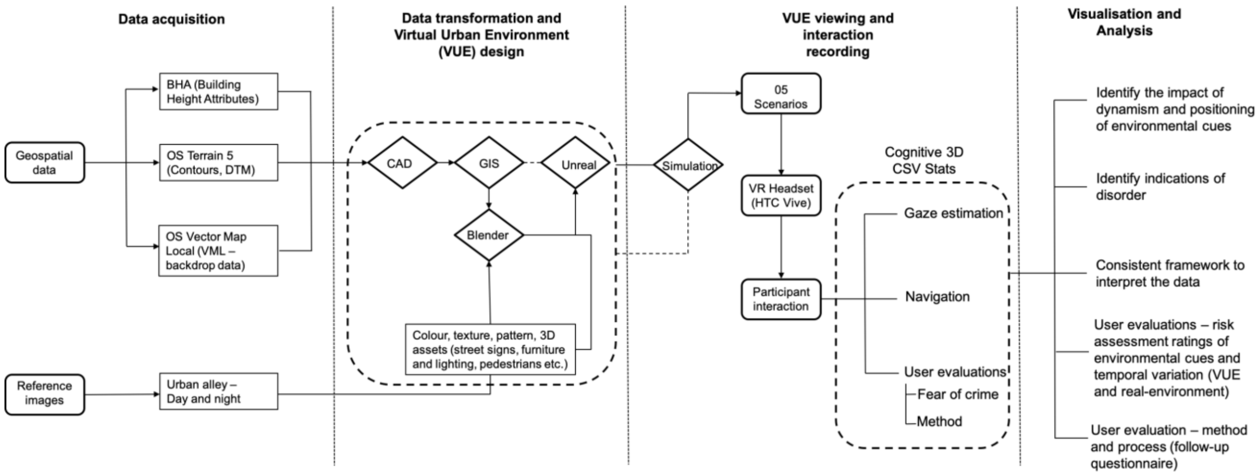


Figure 3.1: Experimental framework using VR to capture context-specific and momentary perceptions of criminal risk

As illustrated in Figure 3.1, the experimental framework proposed in this chapter is composed of four stages. The expected outcome of the above framework, which is also the first outcome of this study is an optimised virtual urban environment (VUE) that closely represents a real-environment urban alley, and provides the required level of immersion, interactivity, and presence for the participants. Figure 3.1 is an integrated outcome of the research design, starting from the fear of crime and urban design integrated conceptual framework to the review of the suitability of different techniques, and then to the design of the experimental framework.

The first stage i.e., data acquisition includes capturing images of an urban alleyway that can be used as a reference for building the VUE model in Unreal Engine 4. Next is to obtain geospatial data layers required to build a 3D city model and this can be of any geographical location because this step facilitates building the gaze functions on a 3D test model prior to integrating these in the main virtual environment. Types of geospatial data and data sources are given in Table 3.2 below:

Table 3.2: Geospatial data and data sources for building the 3D model of the virtual urban environment

Data Type	Data Source
Building Height Attributes (BHA)	Edina Digi Map
OS Terrain 5 (Contours, Digital Terrain Model – DTM)	Ordnance Survey
OS Vector Map Local (VML – backdrop data)	Ordnance Survey

After building the test model, this is transferred to the Unreal Engine 4 to build and test the gaze functions and other technical components. This includes testing the eye level from the ground, navigation speed, aligning navigation directions on the VR controllers, and testing the data flow. Due to its flexibility, this experimental framework allows for using the data transformation steps in different orders other than the one presented in Figure 3.1. For example, in the case where a study uses an existing 3D city model, data transformation from CAD to GIS becomes optional as the 3D model can be exported to Unreal Engine 4 directly either prior to or after rendering in Blender, which is a free and open-source 3D computer graphics software used for creating visual effects, motion graphics, and mainly rendering 3D models. The model can then be prepared for simulations in Unreal Engine 4. The third stage is where the participant engagement takes place. This stage involves the use of VR hardware, in this case, the HTC Vive HMD (VR headset) with two VR controllers as illustrated in Figure 3.2.

Figure 3.2: HTC Vive VR Head Mounted Display and Controllers

VR simulations of alleyway scenarios of daytime and night are presented to the participants at this stage for them to experience a walkthrough in each of the scenarios. The scenarios are designed considering the established environmental cues (both environmental design and incivilities) in the previous chapter (Chapter 2), two key urban design elements i.e., visual entrapment and visual permeability that are presented in the conceptual framework, and finally, the temporal dimension i.e., time of the day. Building on the conceptual framework in the previous chapter, a total of 05 scenarios are designed, ensuring that these represent the real-environment alleyway and its functions as closely as possible i.e., a great level of realism and dynamism. The output data expected from this stage are the gaze data i.e., gaze direction, location and duration, surveyed results on user evaluations about their perceptions of criminal risk and the stand-alone VR application. Additionally, each walkthrough is recorded during the experiment via screen recording, which provides a better representation of the walking behaviour of each participant, for example, changes in walking speed, direction, or pauses within the virtual reality simulation.

The fourth and final stage comprises the visualisation and analysis of the acquired gaze data and survey results based on the following themes:

- Identifying the impact of dynamism and positioning of environmental cues.

- Examining the relative significance of environmental cues in people calculating criminal risk.
- Establishing a consistent framework to interpret the data.
- User evaluations for risk assessment ratings of environmental cues and spatiotemporal variations in the perception of criminal risk in the virtual and real environment (includes both VR data and survey results).
- User evaluation for the stand-alone VR tool and the process of the VR study (includes survey results).

Visualisation and analysis of VR data and survey results are done using R Studio and the results are explained with reference to academic literature in Chapters 5 and 6. The four stages are explained in detail in the next chapter (Chapter 4) as this is the first of three key outcomes of this study. It is also important to note that this study attempts to utilise free and open-source software whenever possible as this improves the replicability and flexibility of the experimental framework presented in this chapter. Table 3.3 summarises the software and hardware that are used in this empirical study.

Table 3.3: Summary of the software and hardware employed in the empirical study

Category	Name of the Software
Real-time 3D environment design applications	UNREAL ENGINE blender
Geospatial applications	QGIS
Statistical computing and graphics for visualisation and analysis	R
Hardware	HTC Vive VR kit – headset, controllers and base stations Desktop computer with a high-performance GPU (Nvidia GeForce 1060 or above) Laptop computer with a high-performance GPU (Nvidia GeForce 1060 or above)

3.4.2 Participant recruitment

While studying men's perception of criminal risk is also valuable, focusing on women's perception is crucial due to the specific safety concerns and challenges they encounter in public spaces. Women often face a higher risk of various forms of harassment, assault, and violence, which can significantly impact their daily activities and overall well-being. Moreover, women often perceive higher risks of victimisation (Ferraro, 1996; Pain, 2001; Franklin et al., 2008; Johansson and Haandrikman, 2023), influencing their lifestyle choices and restricting their freedom of movement, which underscores the need for measuring these perceptions of criminal risk and effective crime prevention strategies. Understanding how women navigate and perceive urban environments can help identify the unique factors that contribute to their perceptions of criminal risk. By recognising these distinct experiences, researchers and policymakers can develop targeted interventions and urban planning strategies that address the specific safety needs of women. This can contribute to creating more inclusive and secure public spaces that promote gender equity and foster a sense of safety for all individuals. Additionally, studying women's perceptions can offer insights into the social, cultural, and structural factors that contribute to the gendered experience of safety in urban settings, leading to more effective and tailored approaches to enhancing overall community well-being.

For this study, a representative sample of young women was considered. Selecting a single participant group or social group enables the study to standardise the variable, which is the perception of criminal risk. Further, it allows to discount variance in response that might be generated by gender or age variation as explained in Chapter 2.

Participants were recruited by circulating a flyer (both online and offline) (see Appendix A) with information on the VR study and a barcode for the online registration form (screening survey) which was designed using Microsoft Forms. Flyers were circulated among students in all four faculties of the university: Arts and Humanities, Business and Law, Health and Education, and Science and Engineering. The main method of circulating the flyer was through faculty email lists targeting students of each faculty. Additionally, flyers were also posted on departmental notice boards. The sample (N = 30) was composed of 30 young women aged between 19 and 30 years (an average of 25 years). Most of the participants were university students, including both postgraduate taught and research (n = 25).

Table 3.4 summarises the demographic information collected from participants in the screening survey, detailing the distribution of age, gender, country of origin/birth, and ethnicity. According to Table 3.4, the largest ethnic groups were Asian or Asian British - Indian and Asian or Asian British - Chinese, each making up 20% of the sample. Other notable groups included individuals from other Asian backgrounds (16.67%) and White - English, Welsh, Scottish, Northern Irish or British (13.33%). The remainder of the participants were from various ethnic backgrounds, each constituting smaller percentages. The majority of participants were from China (20%) and the United Kingdom (16.67%). Other countries of origin included India (16.67%), Sri Lanka (13.33%), and several others each comprising smaller percentages. Furthermore, the country of origin/birth of the participants presented a considerable geographic variation, which impacted the findings of the study positively as their perceptions of criminal risk varied depending on country-level exposure and context.

Table 3.4: Summary of demographics captured in the participant screening survey

Demographic Variable	Category	Frequency	Percentage
Age (years)	19 - 24	14	47%
	25 - 30	16	53%
Gender	Female	30	100%
Country of origin/birth	United Kingdom	5	16.67%
	China	6	20%
	India	5	16.67%
	Sri Lanka	4	13.33%
	Turkey	3	10%
	Bangladesh	1	3.33%
	Nepal	1	3.33%
	Kenya	1	3.33%
	Brazil	1	3.33%
	Bulgaria	1	3.33%
	Nigeria	1	3.33%
	Canada	1	3.33%
Ethnicity	Asian or Asian British - Indian	6	20%
	Asian or Asian British - Bangladeshi	1	3.33%
	Asian or Asian British - Chinese	6	20%
	Any other Asian background	5	16.67%
	White - English, Welsh, Scottish, Northern Irish or British	4	13.33%
	Any other White background	3	10%
	Black, Black British, Caribbean or African	2	6.67%
	Mixed or multiple ethnic groups	2	6.67%
	Other ethnic group	1	3.33%

3.5 Design of the follow-up survey

It is evident from the academic literature that combining VR methodologies with traditional survey methods can lead to more reliable and comprehensive experimental approaches, and thus, can provide more accurate data (Park et al., 2011). It was deemed necessary to do a follow-up user evaluation representing the criminal risk assessment of environmental cues to determine to what extent their perceptions of criminal risk overlap with their gaze measures. This survey questionnaire (see Appendix C) is administered soon after each participant completes the VR experiment.

For this study, the questionnaire is composed of two sections. The first section begins with personal information such as age, gender, and previous experiences related to fear of crime in general as well as in urban alleys. This is followed by a set of questions connected to personal victimisation and associated risks identified by the Crime Survey for England and Wales (CSEW) such as being mugged or robbed, being sexually assaulted, and being physically attacked, which require the participants to rate from 1 to 5 (5 being very high risk of victimisation). Next, the participants are required to rate the perceived level of criminal risk as provoked by each environmental cue that is determined in Chapter 2 and integrated into designing the virtual alleyways. The questionnaire is designed to allow the researcher to determine any mismatches between the gaze data collected using the VR application and the surveyed results. This is then posed as an open-ended question to allow the participant to explain any differences between their gaze data and survey rankings.

The second section of the questionnaire gathers data about the VR application and the process for validating the experimental framework. This includes questions about the level of immersion and realism, user-friendly and usability, and physical and emotional comfort and convenience of participants. The survey results are discussed in Chapters 5 and 6.

3.6 Setting up the virtual reality laboratory

Setting up the VR laboratory is a crucial step in ensuring the validity and reliability of data collected on the perception of criminal risk, which involves detailed planning and execution. This setup is designed to create an immersive and controlled environment where participants' visual attention can be precisely measured. Key components include selecting an appropriate physical space, procuring and configuring VR equipment, designing realistic VR scenarios, and implementing robust data collection and management protocols (Van Gelder, 2023).

The initial step is choosing a suitable physical space. The laboratory should be spacious enough to allow participants to move freely and safely within the VR environment, minimising the risk of physical accidents. Additionally, the room must be quiet and free from external distractions to ensure participants remain focused on the VR experience (Baños et al., 2004). The space must also have adequate electrical outlets and reliable internet connectivity to support the VR system and associated data collection devices. Implementing safety measures such as clear boundaries enhances participant comfort and prevents accidents, ensuring a secure environment for immersive experiences. For this study, a VR laboratory in Neuro-Cog Labs (Neuropsychobiology Affective and Cognitive Research Laboratories) in the Department of Psychology was deemed suitable in terms of space and the availability of VR equipment. Figure 3.3 illustrates the VR laboratory setting selected for the purpose of this study, which includes two VR base stations placed diagonally across the laboratory, a high-performance desktop computer for the researcher to operate the VR system (Figure 3.3(a)), separate space for participants to be seated and engage in the VR experiment (Figure 3.3(b)), and HTC Vive VR head-mounted display and controllers.

(a)

(b)

Figure 3.3: (a) Right-Left angle (from entrance) and (b) Left-Right angle of the VR laboratory setting, including the two base stations and VR head-mounted display

In an effective VUE where users feel present, the users recognise the stimuli as not real. This is referred to as suspension of disbelief (Waterworth and Waterworth, 2001). This can be disrupted by hardware limitations or inconsistent content. Virtual landscapes, objects, and avatars need to align and be consistent with the visual and interactive design of the VUE (Van Gelder et al., 2014). It should also be noted that to create a strong sense of presence in a VR environment, visual realism is less important than other factors. According to Sanchez-Vives and Slater (2005) and Wilson and Soranzo (2015), realism can be more about psychological fidelity, meaning how well the VUE elicits real-life physiological or emotional responses, rather than just high visual fidelity.

Participant interaction and data collection are central to the VR laboratory setup. Clear instructions and a brief training session on using the VR equipment are necessary to ensure participants are comfortable and familiar with the technology. At the same time, a robust data management framework is also essential for integrating and interpreting the collected data. Secure data storage solutions with regular backups and restricted access ensure the integrity and confidentiality of the data. By meticulously setting up the VR laboratory with attention to the above-mentioned details, it is possible to create an effective environment for conducting a VR study, leading to more accurate and meaningful findings. After the VR laboratory was set up, the data collection took place over two weeks from mid to end of June 2022.

Further, ethical and safety considerations are paramount in setting up the VR laboratory. Participants must provide informed consent, understanding the nature of the VR experience and any potential risks involved. Strict confidentiality protocols should be in place to protect participant data, with secure storage and handling practices. Clear procedures must be in place for addressing any discomfort or emergencies during the VR study to ensure participant well-being throughout the study (Beauchamp and Childress, 2001). The next section (Section 3.7) explains ethical practical considerations in detail, in terms of acquiring data on the perceptions of criminal risk, using VR, and the health and safety of the researcher and participants involved.

3.7 Practical and ethical considerations

As explained in this chapter, it was deemed necessary not only to establish an experimental framework that addresses the shortcomings of traditional survey methods used in fear of crime research but also to ensure the safety of both researchers and participants throughout the study. Whilst the level of realism can be compromised to a certain extent in virtual urban environments (Hamad and Jia, 2022), it was not the best option to conduct the study in the real-environment by bringing the participants to an urban alley twice a day – during the day and after dark. This would pose a significant risk to the safety of everyone involved. Therefore, conducting the experimental study in a more controlled lab environment was necessary in order to ensure maximum safety and protection of the participants, researchers and the devices used.

Research ethics is a core aspect of the research; thus, it is important to look into some of the major ethical considerations in the research design. The key considerations in this research work to protect the rights of research participants, enhance research validity, and maintain scientific integrity. Notions of what is acceptable and unacceptable in terms of risk assessment measurements and data collection methods, and what questions trigger participants are constantly under review as ethical values and social norms evolve (Fraga, 2016). Arising from its nature, specific issues within studies of the perception of criminal risk must be acknowledged as VR simulations of alleyways or some survey questions may cause participants to resist taking part in the study due to the fear of being triggered. This is mostly applicable to participants who may have been a victim of crime in the past. Therefore, researchers need to be prepared to handle such situations with appropriate caution, care and confidence. Throughout the VR study, every effort was made to assure participants that they were in control as this helped minimise any external impact on their perceptions. It was conveyed to the participants as part of the VR study protocol that they were free to take a break in between if the VR scenarios or the follow-up survey were triggering or evoking negative emotions.

Further, when obtaining written informed consent for participating in the study, participants were assured about their ability to freely opt-in or opt out of the study at any point in time. Prior to consenting to participate, the research was explained to the participants, including the research aim, objectives, questions, risks, methods, and funding behind the study before they agree or decline to take part. From participant registration to analysing the results, participants' identifiable data have been stored and managed according to the Privacy and Data Protection Policy of the Manchester Metropolitan University, and measures have been taken to anonymise such data at all stages of the research.

Whilst some participants may experience physical discomfort or motion-sickness during the VR experiment, every effort has been made to assure that physical, social, psychological and all other types of discomforts or harms were kept to an absolute minimum.

In addition to the above-discussed considerations, a more common and timely ethical consideration that overlaps with practical considerations is the global pandemic. Due to the nature of this study, it is imperative to acquire primary data from the participants to understand their perceptions of criminal risk in urban alleys. However, the three national lockdowns and the city-level health and safety restrictions caused an inevitable delay of over 10 months to the research. During this period, it was decided to move forward some of the writing up tasks as the university facilities were closed.

Therefore, building on the three questions - which methods most effectively fit the aim and objectives of the research, what are the strengths and restrictions of each of the methods that were reviewed, and what are the potential risks when using each of these methods, above-discussed practical and ethical considerations have informed the proposed VR experimental framework in this study. Implementing these ethical standards not only protects participants but also enhances the credibility and integrity of the research.

3.7 Conclusion

This chapter has sought to outline the data, methods, and the VR experimental framework deployed in this thesis to answer the two primary research questions relating to alleyway design and usage, and its impact on women's perception of criminal risk; and the potential of VR simulations to uncover people's momentary and context-specific perceptions of criminal risk. Consideration was also given to an extensive review of the traditional and emerging methodologies, leading to the proposed VR experimental framework. An introduction to VR and related terms was provided, with particular consideration given to the design of an experimental framework that not only overcomes the shortcomings of traditional methods but also is interdisciplinary and replicable. An outline of the participant recruitment was given. The merits and shortcomings of different techniques were discussed, with a decision being made to use VR along with eye-in-head gaze data and a follow-up survey. An argument was made for the use of eye-in-head gaze data as opposed to eye-tracking data to investigate people's perception of criminal risk through visual attention, as a solution to the numerous technical and practical interruptions caused, and to maintain data integrity and accuracy. An experimental framework was proposed for fulfilling two of the objectives: to develop a novel approach to obtain momentary and context-specific perceptions of criminal risk, and to critically evaluate the efficacy of VR as a tool to explore women's perceptions of criminal risk. The next chapter will report the first outcome of the thesis, which is the design and development of a gaze-based VR simulation of alleyways. It will begin with recollecting the stages of the experimental framework to augment the methodological arguments made in this chapter.

Chapter 4

Development of a gaze-based virtual reality simulation of alleyways

4.1 Introduction

The previous chapters have identified two major shortcomings in existing approaches to measuring the perception of criminal risk. Specifically, they have highlighted the failure of existing methodologies to capture both momentary and context-specific perceptions of criminal risk. To remedy these gaps, this chapter explores the potential of a gaze-based VR simulation to capture momentary and context-specific perceptions of criminal risk. In approaching this challenge, the argument has been made for treating the perceptions of criminal risk, environmental design, and incivilities as related but theoretically distinguishable phenomena. As such, it is useful to explore the potential of developing tools that can acquire momentary and context-specific perceptions of criminal risk in real time as people navigate urban spaces with different visual cues, including design elements and incivilities. To this end, this chapter explores the possibility of deploying a gaze-dependent VR methodology augmented by a follow-up questionnaire survey (see Chapter 3, Section 3.5) to overcome the shortcomings of traditional methods and approaches to measuring the perceptions of criminal risk.

With this in mind, the chapter is structured as follows: Section 4.2 presents the workflow of developing the gaze-based virtual reality simulation, highlighting the suitability of adopting an agile approach. Section 4.3 explains the process of designing the virtual alleyway scenarios, focusing on the association between the environmental design, incivilities and the perception of criminal risk as discussed in Chapter 2. Section 4.4 then illustrates the design and implementation of the gaze-based virtual reality simulation of alleyways, focusing on its core features and functions, and testing and evaluation. Finally, Section 4.5 reflects on the proposed approach, highlighting its novelty through data and methodological triangulation, to capture context-specific and momentary perceptions of criminal risk.

4.2 Virtual reality simulation development life cycle

VR simulation has emerged as a transformative technology with far-reaching implications across various sectors, revolutionising the way we perceive, interact with, and comprehend the environment around us. Its significance transcends mere entertainment, as virtual reality simulations have found practical applications in fields such as education, training, healthcare, sports, psychology, geography, and beyond (Gulec et al., 2017). By enabling users to immerse themselves in realistic and interactive digital environments, this technology has the potential to bridge geographical distances, evoke emotions, capture people's perceptions, and facilitate intricate simulations that are otherwise challenging or impossible to recreate in the real world.

The process of developing a virtual reality simulation often resembles the software development process, and as a result, it follows software development methodologies. These methodologies are also known as Systems Development Life Cycles (SDLC), which are conceptual frameworks that break down the process of software development into stages from inception through to system launch and maintenance (Ruparelia, 2010). Commonly used conventional development life cycle models are the waterfall model, iterative model, prototype model and spiral model (Saini and Kaur, 2014). The waterfall model, which is a sequential development approach, has been criticised for its inability to accommodate changing requirements and customer feedback, often resulting in high project cost and risk (Govardhan, 2010; Alshamrani and Bahattab, 2015; Gurung et al., 2020; Diansyah et al., 2023). The iterative model, while addressing some of the limitations of the waterfall model, is also criticised for difficulties in managing multiple iterations effectively and increased complexity with each iteration (Gurung et al., 2020; Diansyah et al., 2023). The prototype model, although useful for obtaining early feedback, may lead to an overemphasis on the prototype itself, potentially diverting attention from the final product (Prabowo et al., 2022). Finally, the spiral model, despite integrating risk analysis and management, can become time-consuming and costly due to its emphasis on exhaustive planning and evaluation at each phase, potentially delaying the final product release (Gurung et al., 2020). These critiques underline the significance of adopting more flexible and adaptive methodologies, such as Agile approaches, to effectively manage the evolving requirements of modern software development projects. Therefore, this study adopts an Agile approach as illustrated in Figure 4.1, to allow for incremental development of the gaze-based virtual reality simulation and frequent testing of the accuracy of the functions such as gaze tracking and navigation. Moreover, this approach ensures flexibility, modifiability, adaptability, and maximum usability of the virtual reality simulation through enabling frequent interaction with users or participants through all phases of this development life cycle, which are key to developing a virtual reality simulation (Pereira and Russo, 2018).

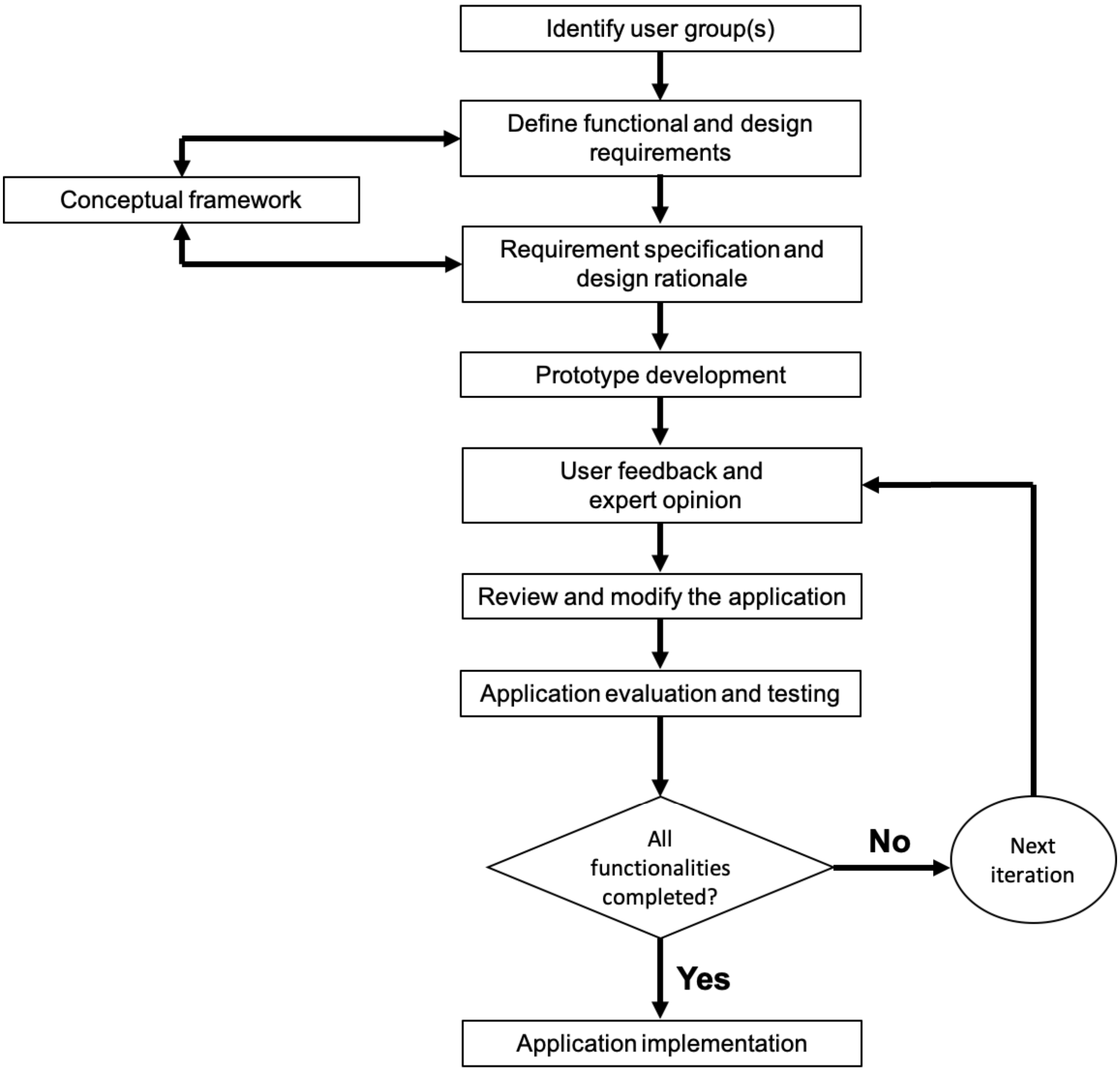


Figure 4.1: Agile approach adopted in developing the gaze-based virtual reality simulation

The agile model ensures user satisfaction by engaging them throughout every stage of the development process and accommodating last-moment changes as opposed to the above-explained traditional SDLC models. This approach also follows an incremental approach to software development (Bogdan et al., 2016), rather than following sequential predetermined phases. An Agile approach ensures continuous testing of the application or software and maintains constant collaboration between users and developers (Pereira and Russo, 2018). For this reason, employing an Agile approach enables swift adjustments to the gaze-based virtual reality simulation in response to the frequent changes in the functions and features of the alleyway scenarios, which occur at simulation-testing stages, including the pilot study.

Moreover, this study, as it uses a virtual environment to acquire gaze data, requires a realistic representation of the alleyways, including its design and visual cues i.e., incivilities, to establish a strong correspondence between the virtual environment and the real-world setting (Li et al., 2019). In the context of examining the association between alleyways and the perception of criminal risk, a lively alleyway with realistic simulation of pedestrians and street lighting, along with other relevant design elements and incivilities is key for fostering an immersive environment, which the participants feel fully involved in the experience (Schrom-Feiertag et al., 2020).

To achieve such realism in the virtual alleyway simulation, it is required to obtain participant or user feedback at different stages of the simulation development process. To this end, the Agile approach adopted in this study obtains user or participant feedback in two phases i.e., two iterations to refine the simulation. The first iteration presents the functional aspects that were built into a three-dimensional (3D) model of an alleyway using Unreal Engine 4, which is a game development application (also known as a game engine). For this phase, a group of five participants, comprising of two academics in urban studies and immersive technologies, and three women participants (voluntary) from the university were invited to test the simulation prototype. The second iteration involved a pilot study with four more women participants from the university, who were invited to test the modified prototype and feedback on the usability, feasibility, and functionality (e.g., navigation speed, viewpoint, and duration to complete all alleyway scenarios), and the level of physical and emotional comfort (e.g., feelings of dizziness and physical space for body movements) while engaging in the virtual reality experiment. These two stages are further explained in upcoming sections. Furthermore, defining functional and design requirements, and design rationale as given in Figure 4.1 are dependent on the conceptual framework that was established in Chapter 2. This Agile approach spans stages one, two, and three of the methodological framework presented in Chapter 3. These stages, from designing the 3D model of alleyways to building the core features and functions of the simulation, and testing the prototype are explained in Sections 4.3 and 4.4 of this chapter.

4.3 Design of the virtual reality simulation

Designing a virtual reality simulation of alleyways to probe women's perception of criminal risk requires a thorough approach to both technological intricacies and psychological nuances. Therefore, the simulation would need to realistically recreate the sensory experience through visual cues, for example, navigating poorly lit, alleyways while integrating the environmental cues. These environmental cues include incivilities and environmental design elements, including streetlighting that were discussed in Chapter 2. Additionally, it is crucial to incorporate a diverse range of scenarios of alleyways, reflecting potentially different levels of perceived criminal risk to explore in what ways these environmental visual cues, impact their perception of criminal risk in different contexts and moments. This includes designing scenarios depending on the time of day, the presence of both social and physical incivilities, and environmental design elements such as visual permeability, visual entrapment, and street lighting. By building these dimensions to the VR simulation, it would allow us to explore not only the significance of each visual cue, but also their relation to one another i.e., the relative significance. To ensure a comprehensive understanding of women's perceptions of criminal risk, the design should also allow for gathering real-time feedback, enabling participants to express their feelings, concerns, and any changes in perception as the simulation progresses (Bailenson, 2018). By integrating these insights into the design of this virtual reality simulation, it is possible to provide valuable data to inform urban planning strategies around improving women's perceptions of criminal risk in alleyways and other urban spaces.

4.3.1 Conceptual design of the alleyway scenarios

The first step of developing the virtual reality simulation prototype is to conceptualise the design of alleyway scenarios, considering the visual environmental cues presented in Chapter 2, and referred to in Section 4.3. This requires careful consideration of several factors, including the number of scenarios, level of detail (Neo et al., 2021) in the alleyways, positioning of visual environmental cues within each scenario, length of each alleyway, which also relates to the duration of a single walkthrough of a scenario, speed of navigation (Neo et al., 2021), and the mix of visual cues for each scenario. Considering these factors when designing the alleyway simulations would enable us to understand which cues stand out when an individual is presented with a mix of visual cues that impact their perception of criminal risk. To this end, drawing upon the incivilities model (Sampson, 2009; Chataway and Bourke, 2020), prospect-refuge (Appleton, 1975; Cozens and Sun, 2019), and building on the importance of the environmental design of alleyways i.e., visual permeability and visual entrapment (Baran et al., 2018) and street lighting, and their relation to the perception of criminal risk, this thesis focuses on five key visual cues as demonstrated in Table 4.1 for the design of alleyway scenarios.

Table 4.1: Visual cues considered in the design of virtual alleyway scenarios

	Visual permeability	Visual entrapment	Social presence		Maintenance		Street lighting	
			Men hanging out	Moving people	Graffiti	Rubbish and litter	Well-lit	Poorly lit
Scenario 01	✔	✘	✔	✔	✔	✔	Daytime	
Scenario 02	✘	✔	✔	✔	✔	✔	✔	
Scenario 03	✔	✘	✔	✔	✔	✔		✔
Scenario 04	✔	✘	✔	✘	✔	✔	Daytime	
Scenario 05	✔	✘	✔	✘	✔	✔	✔	

Social presence (see Table 4.1) is a crucial visual cue to consider when examining the perception of criminal risk. For example, presence of people can either be perceived as a criminal risk or not depending on what they are doing, where they are looking, and where they are going (Seymour et al., 2010; Schlund et al., 2017). Building on the previous theories of social disorder, this study considers the dynamic nature of social presence in an alleyway. Thus, social presence is further expanded into two variables: first, which represents groups of men hanging out around the corners of the alleyways, and second, which is pedestrians i.e., people moving through the alleyways. As depicted in Table 4.1, maintenance reflects the presence of physical incivilities such as rubbish and litter lying around, and graffiti, which reflect vandalism. A thorough description of the five scenarios illustrated in Table 4.1 is given in Chapter 5, in response to discussing the data generated by the VR study.

4.3.2 Core features and functions

As the second step, it was deemed necessary to build the core functions of the VR simulation prior to designing and building the virtual alleyway scenarios. This is reflected in the first stage of the methodological framework established in Chapter 3. The data used to build the core features and functions of the VR simulation is acquired from the open data storage of Edina Digimap in Geodatabase format. This data can be read by Quantum GIS (QGIS) or any Geographical Information System (GIS) in its raw format without needing to process further.

As illustrated in Figure 4.3, Building Height Attributes (BHA) provide a set of height attributes with a building theme within the Ordnance Survey Master Map Topography Layer. Following three datasets were downloaded for Manchester from Edina Digimap using the Ordnance Survey (OS) data download application:

- BHA data (BHA data is found in the OS MasterMap category) in File Geodatabase format.
- OS Terrain 5 DTM (this was used as the base (surface) height for the area).
- OS VectorMap (this was used as backdrop data).

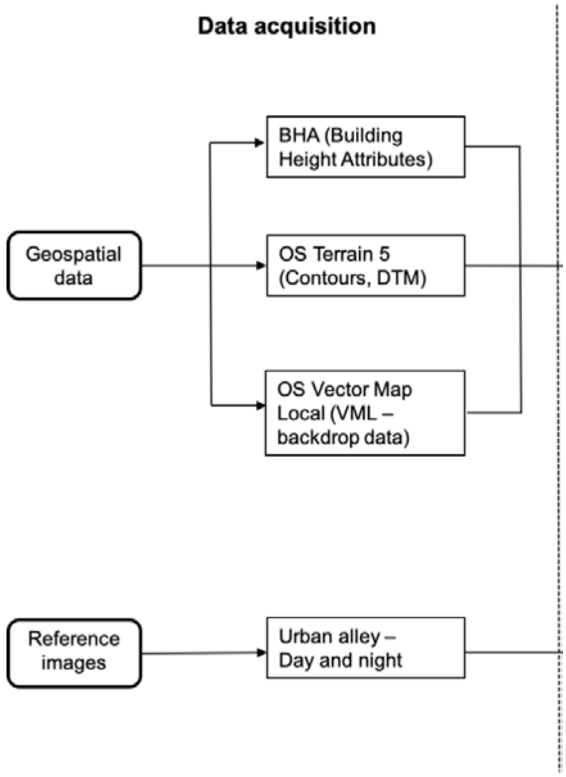


Figure 4.2: First step of the methodological framework (see Chapter 3)

Secondly, these data layers were opened in the AutoCAD application for cleaning and pre-processing. This step was necessary to ensure unwanted or irrelevant data were erased and the 3D model was of higher resolution with an affordable file size for further processing in Revit and GIS applications. Figure 4.3 illustrates the 3D model with 'Level of Details – LOD1', which was cleaned and visualised in the AutoCAD application.

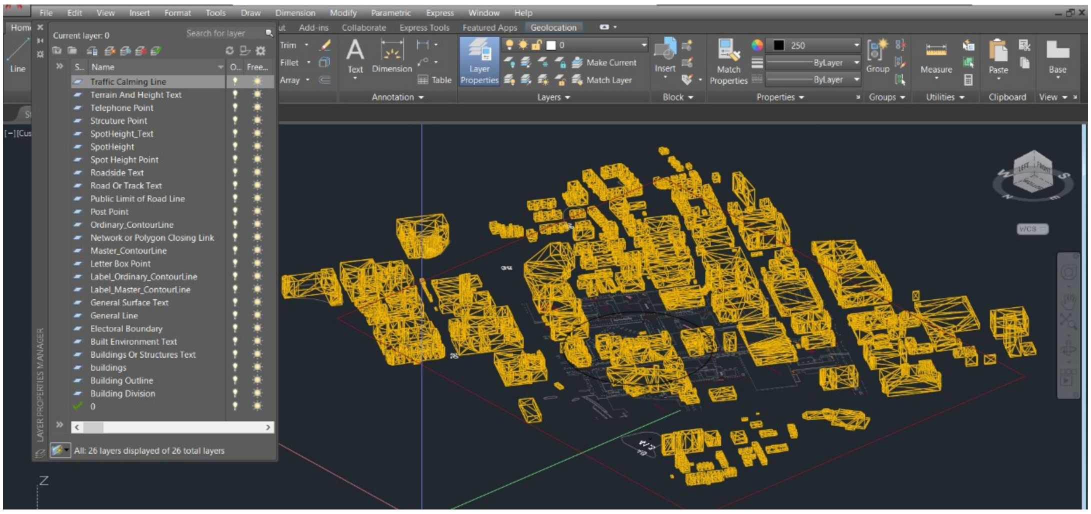


Figure 4.3: Geospatial data layers for Manchester overlaid, cleaned and visualised in AutoCAD application

BHA data is overlaid on the OS Terrain 5 DTM and OC VectorMap was used as a backdrop for this 3D model. Data transferring between AutoCAD, Revit and Unreal Engine 4 game development applications has been made easy as all these applications support direct exporting of 3D models to FBX format, which is supported by Unreal Engine 4. Thirdly, the model was exported to the Revit application for adding basic environmental features such as trees and roads (see Figure 4.4), to facilitate building the core functions of the virtual reality simulation, which are gaze tracking and navigation. Figure 4.5 presents a 3D view of the initial model prior to exporting to Unreal Engine 4.

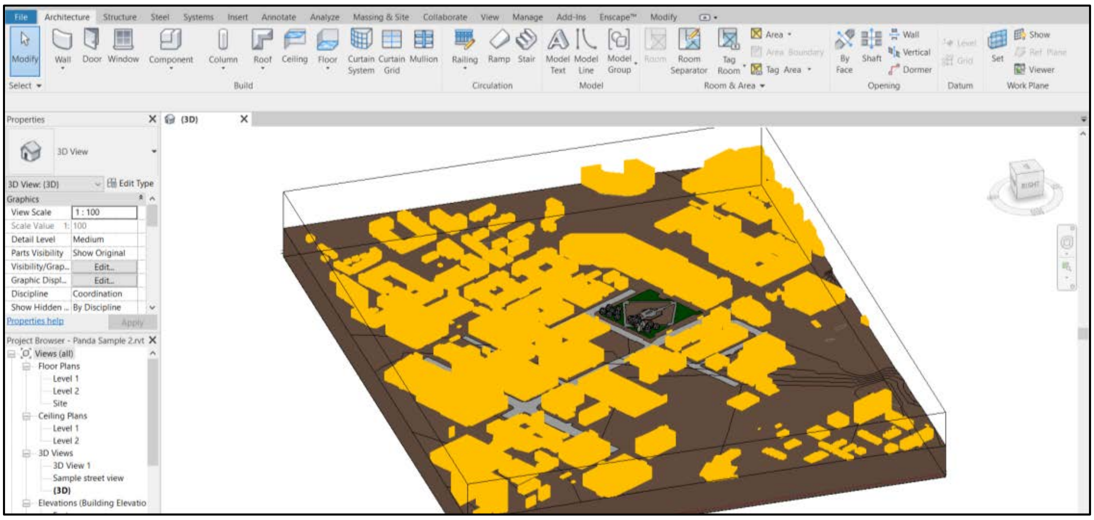


Figure 4.4: 3D model of part of Manchester, with trees and roads added to a portion of the model to facilitate building the core functions of gaze tracking and navigation

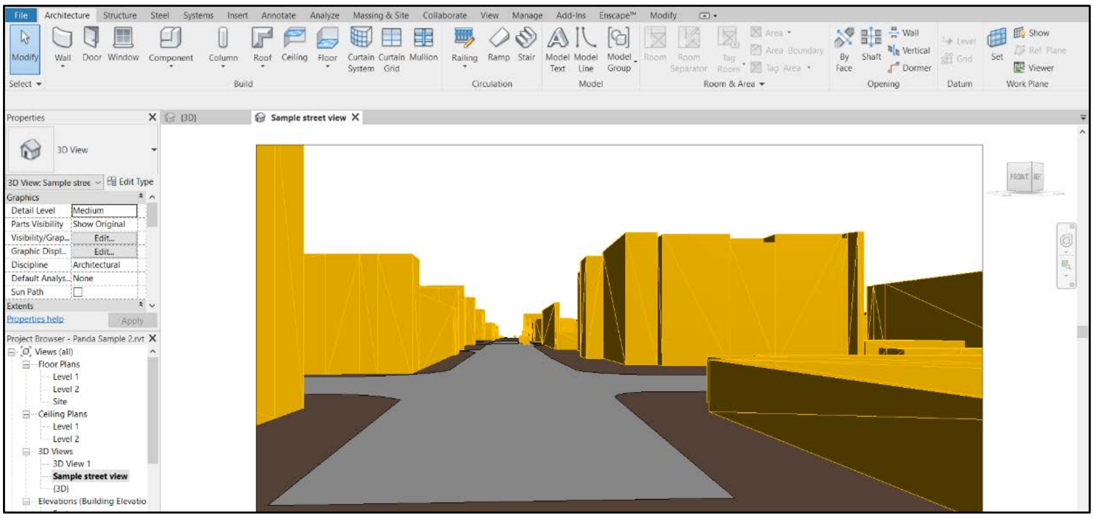


Figure 4.5: Street view of Manchester 3D model

This model was then exported to an FBX (a proprietary format owned by Autodesk) file to open and visualise in the Unreal Engine 4 application. The importance of this step relies on the effectiveness and efficiency of using a Gaming Engine like Unreal Engine 4 for building the required functions in the virtual reality simulation. Prior to explaining the next steps, it is effective to understand the capabilities of Game Engines, including Unreal Engine.

Since the rise of free and open-source (FOS) game engines such as Unity, Unreal Engine, and CryEngine, 3D spatial representations have reached unprecedented levels of immersion. Integrating a player-controlled avatar in these virtual and non-virtual gaming environments allows users to perceive a constructed virtual space from a first-person perspective, mimicking a real-world experience (Florian et al., 2020). Users have the freedom to navigate through this virtual space using keyboard, mouse, or controller inputs. Unlike conventional 2D visualisation methods, game engine-based environments offer nearly limitless perspectives (Keil et al., 2021). In recent years, leading game engines such as Unity and Unreal Engine have facilitated the integration of VR head-mounted display (HMD) compatibility into these virtual environments. As a result, users can experience these environments from an immersive 3D viewpoint, with the ability to translate real-world movements into the virtual environment (Edler et al., 2018). This virtual reality perspective can completely detach users from any distracting elements of the real-world, thereby enhancing the overall immersive experience.

Moreover, game engines bring forth a host of interactive, animation, and simulation possibilities that were previously unavailable in 2D or earlier 3D spatial representations (Ferworn et al., 2013). These interactions can include actions such as adding, removing, picking up, and moving objects, and triggering visual or auditory effects through pressing keys or movement within virtual environments (Keil et al., 2019). Modern game engines also employ models that enable realistic simulation of dynamic 3D sounds, lighting, and gravity (Edler et al., 2019). These capabilities position game engines as suitable solutions for developing different geographic and spatial visualisations and environmental simulation scenarios. Consequently, virtual 3D environments offer opportunities to experience settings that may be otherwise inaccessible due to financial and time constraints, and environmental risks, or non-existent.

To this end, the next steps of building the core features and functions are explained. After the Revit model has been exported to Unreal Engine 4 as an FBX file, it is possible to visualise the 3D model in Unreal Engine 4 application as shown in Figure 4.6.

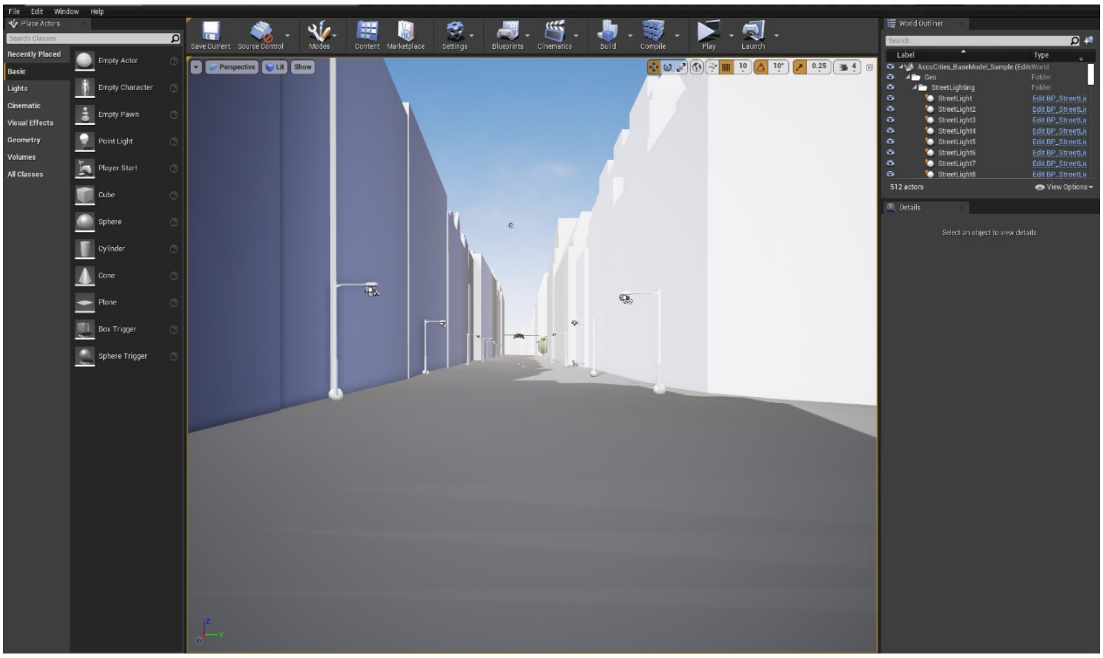


Figure 4.6: Visualising the initial 3D model which was created to build the core functions and features in Unreal Engine 4 application

The next step ensures ample time for testing the functions independently and refine as required. Figure 4.7 depicts the process of building the function for gaze tracking using the blueprint class in Unreal Engine 4. A Blueprint Classis an asset that allows content creators to easily add functionality on top of existing gameplay classes. Blueprints are created inside of Unreal Editor visually, instead of by typing code, and saved as assets in a content package. As such, Blueprint is a high level, visual scripting system that provides an intuitive, node-based interface that can be used to create any type of script events in the Unreal Editor. Although Unreal Engine supports C++ programming language, the ability to simply create design levels and projects using blueprints makes Unreal Engine 4 accessible and usable to researchers and practitioners outside the gaming development industry. Therefore, a person without prior game development experience can create entire games without writing a single line of code, using the Blueprints Visual Scripting system. Thus, combined with an easy-to-use interface, it is possible to get a prototype up and running in a short period of time.

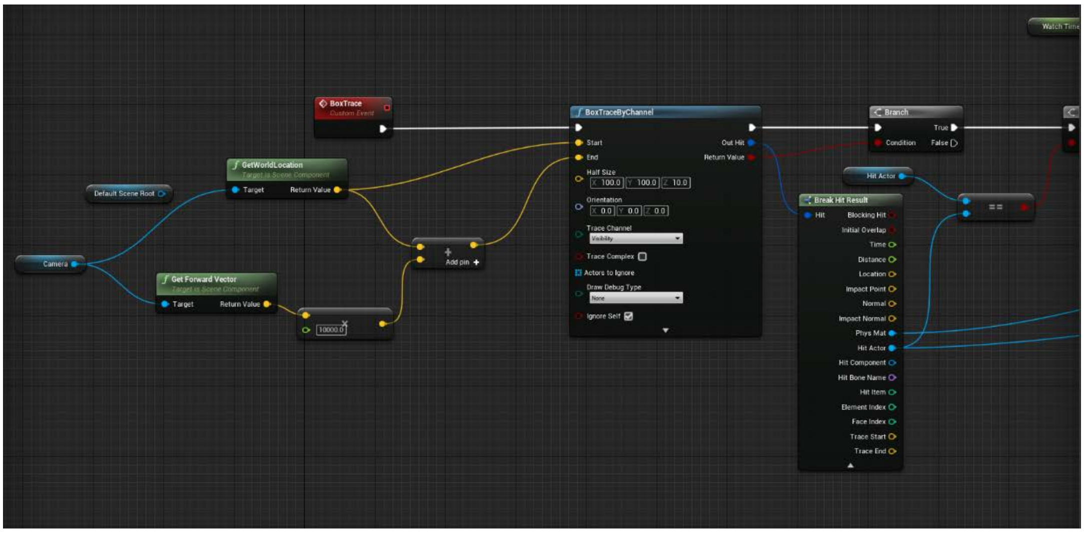


Figure 4.7: Blueprint class for gaze tracking function in the virtual reality simulation of alleyways

Eye-in-head gaze movements are significant in the context of human-computer interactions (HCI). For example, where an individual directs their gaze serves as a strong indicator of attention and interest, thereby presenting an opportunity to utilise them as both input and output data (Sidenmark and Gellersen, 2020). Building on the importance of eye and head coordination in gaze shifts as discussed in Chapter 3, an event, namely Box Trace (see Figure 4.7) is created to call in the necessary function for tracking and tracing user's gaze direction and duration. The function, namely Box Trace by Channel is called in the Box Trace event. These tracing events and functions offer a method for reaching out to the objects present in the virtual space and receiving feedback on what is present along a line segment i.e., line of sight. Traces and trackers in Unreal Engine 4 trace a line segment between two endpoints, for example, start and end points. When tracking eye-in-head gaze shifts using virtual reality, a line trace may not suffice as some objects or actors (for example pedestrians) can go untraced. Therefore, it is possible to use a Shape Trace, for example a Box Trace in this study, for acquiring gaze data of the participants. The feedback from the trace event reports any actors or objects that it hits, for example, if a Box Trace event is called to trace the objects a participant is looking at for more than a second, this event records all the objects that the participant looked at for more than a second, until the end of that alleyway scenario i.e., walkthrough.

Trace by Channel function uses visibility as the trace channel as illustrated in Figure 4.7. Objects or actors can be traced in two ways: first, a trace can be set to record the first object or actor hit by the trace, or secondly, this can record all objects or actors hit by the trace. The Box Trace by Channel function used in this study, sweeps a box along the given line, and finds the objects that responds to the given Trace Channel. Whilst the Box Trace functions similarly to a Line Trace, the former has an added layer of checking and sweeping as it uses a shape to record gaze data as opposed to a line. For this study, the size of the Box Trace is set to 100 (x), 100 (y), 10 (z) as shown in Figure 4.7.

After creating the trace event, criteria for tracing eye-in-head gaze movements were decided (see Figure 8). It was set to record all objects and actors that a user looks at for more than one second (Galley et al., 2015; Paulus and Remijn, 2021) to record gaze duration (in seconds). Gaze duration recorded in this study can be interpreted with reference to existing eye-tracking metrics such as fixations (Galley et al., 2015) and time spent (dwell time) (Paulus and Remijn, 2021).

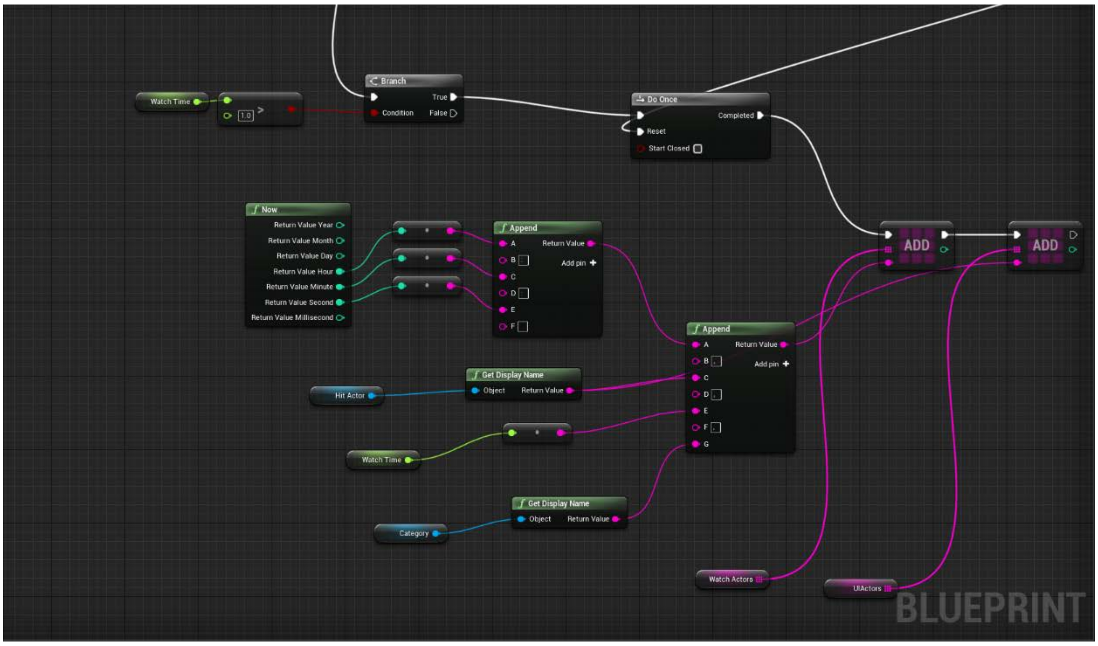


Figure 4.8: Blueprint class to implement the criteria for tracking gaze data

As part of the core function, which is tracing gaze movements (e.g., fixations and dwell time), it was necessary to not only record participants' gaze movements but also to return these values to a readable file, which can then be further analysed. To this end, all recorded data were passed as Comma Separated Values (CSV) to MS Excel, upon completion of each walkthrough. As Figure 4.9 illustrates, this records three types of data: time stamp (real-time) when the gaze movement occurred, watch time (gaze dwell time), and watch actor (visual cue being looked at). The function to save gaze data into a CSV was written using an event namely Event Save Text, which calls in the function to print (write) data as a string value (text) to a CSV file (see Figure 4.10). As Figure 4.10 shows, the directory for saving the CSV file is also given within the above event.

A	B	C
Time	Actor	WatchTime
13:50:35	bp_columns8	3
13:50:46	Talking__1__5	11
13:51:02	bp_columns80	2
13:51:05	bp_columns19	2
13:51:16	bp_columns17_108	2
13:51:22	bp_columns461	2
13:51:27	Talking__1__5	2
13:51:31	bp_columns8	2
13:51:37	Talking__1__5	3
13:51:41	BP_Pedestrian2_5	5
13:51:46	bp_facades34	4
13:51:54	BP_Pedestrian_2	7
13:51:58	bp_columns55	2
13:52:02	bp_columns25	2
13:52:05	bp_facades17	2
13:52:14	bp_columns38	2
13:52:15	bp_columns35	2
13:52:20	BP_Pedestrian7	2
13:52:21	bp_columns38	2
13:52:23	bp_columns40_51	2
13:52:27	BP_Pedestrian3_8	2
13:52:33	bp_columns320	2
13:52:37	bp_columns307	2
13:52:40	bp_columns111	3

Figure 4.9: Sample CSV file of gaze data

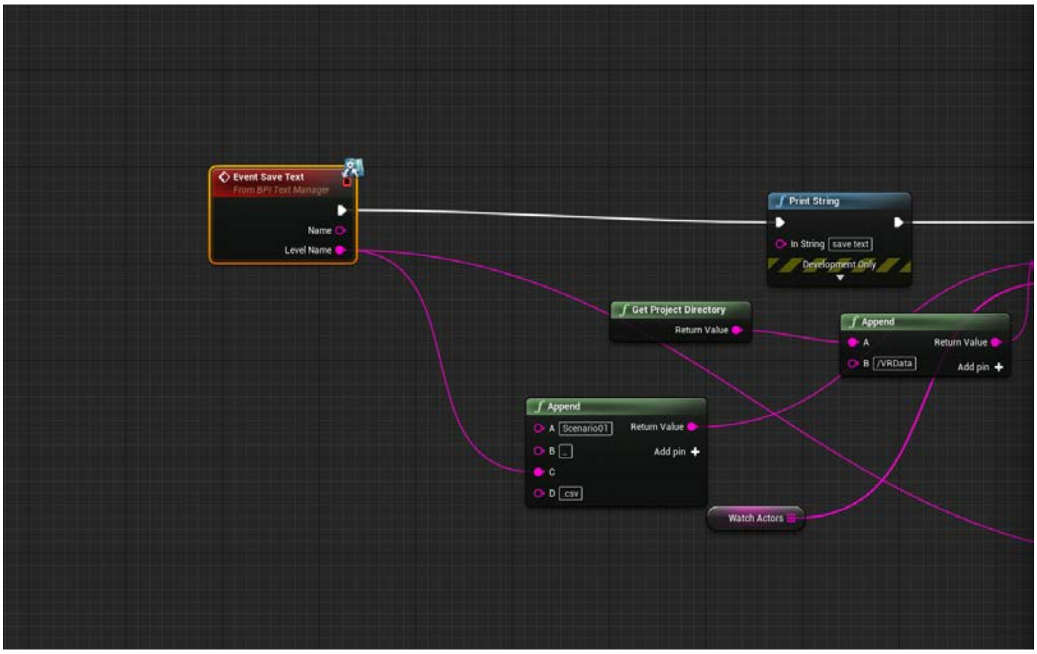


Figure 4.10: Function for saving gaze data to a CSV file

4.3.3 Design of the virtual reality simulation

Further extending on Section 4.3.2, which discussed the potential of using a game engine such as Unreal Engine 4 to build the core functions of the VR simulation, this section, first, discusses potential approaches to design realistic VR simulations of alleyways to probe women's perception of criminal risk.

The relationship between VR and game engines is closely intertwined, as the latter is commonly utilised to craft the captivating experiences used in VR. In an initial examination of Gestalt principles in the aesthetics of products (Valencia-Romero and Lugo, 2017) a combination of a game engine and VR was employed to investigate the assessment of aesthetics within an interactive and realistic setting. Although the tools utilised were not the primary focal point of the research, it was discovered that virtual studies offer certain advantages, such as eliminating the need for actual prototypes, thereby reducing evaluation costs, and enabling the automation of both the presentation of choice sets and the recording of responses. Game engines and their design concepts possess the capacity to simulate a lifelike virtual environment in real time. Within the realm of the construction industry alone, they can produce real-time virtual reality applications that depict architectural and urban design walk-throughs and virtual preconstruction planning processes.

A game engine can offer cutting-edge 3D rendering and interactive capabilities with minimal difficulty. An early instance of this is exemplified in the work of Shiratuddin and Thabet (2002) who utilised a precursor of the Unreal Engine for creating virtual walkthroughs of office buildings. As game engines progressed and became more adaptable, numerous researchers began tapping into their potential. For example, Carpin et al (2007) introduced a robot simulator based on Unreal Engine 2.0 Currently, two engines, Unity3D and Unreal Engine 4 or 5, dominate the market for both gaming and general-purpose applications (Harlan et al., 2020). Originally designed for game development, game engines now facilitate sophisticated visualisations and interactions, enabling their application in diverse fields like construction and architectural design (Kosmadoudi et al., 2013).

Unreal Engine 4 has demonstrated its capability to yield promising outcomes concerning the arrangement and manipulation of geometry, as well as spatial and temporal variables, both within and outside the realm of virtual reality (Ekströmer et al., 2019). With instantaneous display of results, it facilitates reflective discussions. While employing a game engine for virtual reality experiments is a flexible and potentially less time-consuming process, preparing 3D models for precise and comprehensive outcomes can be time-intensive. Recent advancements in geospatial and gaming technologies offer various means of integrating geospatial 3D models with gaming engines, either through a simple plug-in or direct transfer between these platforms. Notably, Unreal Engine 4 supports a workflow toolkit called Datasmith, which assures a reduction in iteration time through the efficient transfer of AutoCAD and GIS data into the Unreal Engine platform.

Thus, with more than one approach to building a virtual alleyway environment being available, it was deemed necessary to determine the most suited approach depending on several factors: familiarity with the software, time constraints on designing the virtual environment and delivering the outputs, accessibility to software, and feasibility. With this in mind, few approaches (see Figure 4.11) that were mostly applied (Shiratuddin and Thabet, 2002; Zhang and Moore, 2013; Edler et al., 2018; Keil et al., 2021) in designing VUEs were reviewed. First, VUEs can be constructed using 3D open data from OpenStreetMap (OSM). This workflow uses all free and open-source software and platforms such as OSM, Blender, and Unreal Engine 4. Secondly, OS and Digimap data can be used to build a 3D model in AutoCAD or Revit (for example, this study adopted this workflow to build data input and output functions in Unreal Engine 4). This model can then be exported to Blender for further 3D modeling and rendering to achieve realism in terms of patterns and textures of the environment. However, this step is optional in this workflow as 3D modeling can be done within Revit software or Unreal Engine 4 itself. Next, GIS or CityEngine can be used to build and export 3D models to Unreal Engine through two plug-ins, namely ArcGIS Maps SDK and Datasmith. These models can then be exported to Unreal Engine 4 either directly or through Blender.

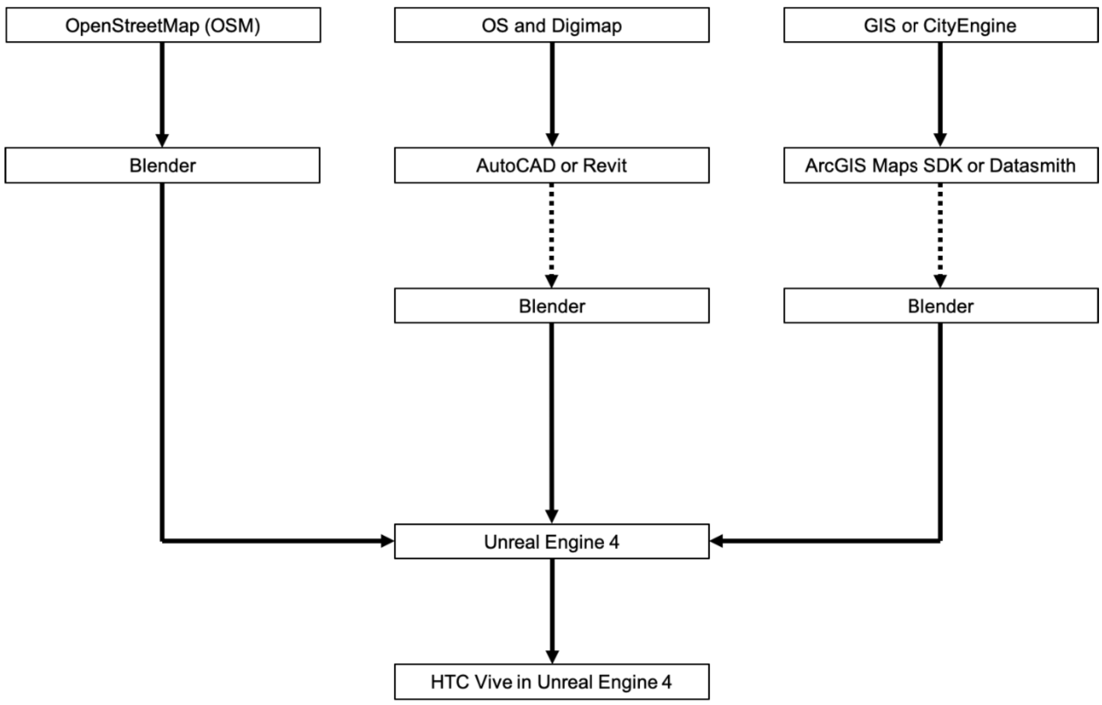


Figure 4.11: Summary of widely applied workflows in constructing virtual urban environments

Summarised from the studies by (Shiratuddin and Thabet, 2002; Zhang and Moore, 2013; Edler et al., 2018; Keil et al., 2021).

Finally, as Figure 4.11 depicts, a virtual environment can be constructed directly in Unreal Engine 4, using assets that are available in Unreal Engine Marketplace. Such assets can either be freely available or purchased, and it offers a wide range of free assets to construct 3D environments, depending on the project requirements. Consequently, considering the above-mentioned factors, including the time it may take to learn more than one new software and the availability of relevant assets in Unreal Engine 4, it was decided to adopt the fourth workflow, in which the virtual urban alley environment was constructed directly in Unreal Engine 4.

It is imperative to design the virtual alleyway scenarios in a manner that mirrors the interactions between the individual and the virtual setting closely resemble those that would occur if the individual were present in the real environment (Neo et al., 2021). Further, for the virtual reality simulation to be ecologically valid, it requires basing the scenarios on common characteristics of real-world alleyways (Jicol et al., 2022). For this reason, the virtual alleyway scenarios are based on an alleyway in Manchester (opposite Printworks, Manchester). Figure 4.12 shows the real-world alleyway which is used as a reference to build the virtual alleyways.

Figure 4.12: Reference urban alley in Manchester at the daytime (left) and at night (right)

Referring to Figure 4.12, constructing the virtual urban alleyways began with choosing a relevant asset from the Unreal Engine Marketplace (UE Marketplace) that was as much similar to the real world, in terms of its textures, patterns, and colours. Thus, the following asset – Victorian Street (see Figure 4.13), was obtained. This has a Blueprint-driven modular design which facilitates construction of the required environment, and place and modify assets. This also allows great flexibility in placing and shaping the roads and sidewalks through its Spline Blueprints. Further, material instances in this project make it easy to control the appearance of the meshes and vertex-paintable materials can be used for creating dirt and water accumulation i.e., puddles in the urban alley.

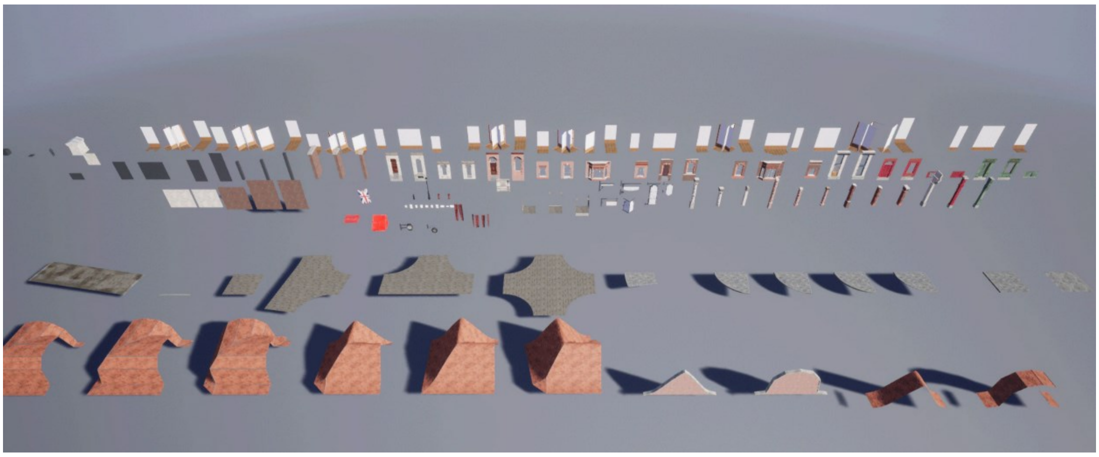


Figure 4.13: Assets in the Victorian Street Unreal Engine project for constructing 3D street environments

The next steps included accessing the above assets through Blueprints located in the 'Blueprints' folder of the project and creating and shaping the urban alleyways (path surface) using Splines (see Figure 4.14). Then, walls, building facades, windows, and doors were created along the alleyways.

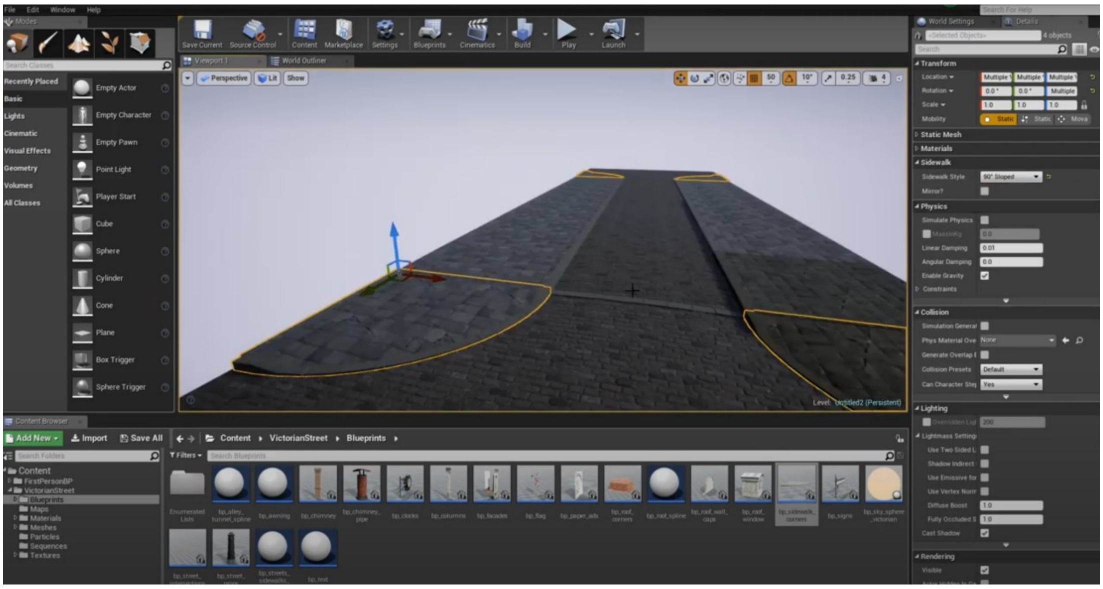


Figure 4.14: Creating and shaping urban alley (path surface) using Spline Blueprints

The above step applied to constructing all five urban alleyway scenarios which are presented in Table 4.2. Upon completion of constructing the urban alleyway for the first scenario, which was visually permeable and had less visual entrapment, other cues were added. These included social presence (both moving people and groups of men hanging out in the corner of the alleyway), graffiti, and rubbish and litter lying around. This scenario (see Figure 4.15) represents a typical urban alleyway in the daytime.

Figure 4.15: Design of the virtual urban alley environment in Unreal Engine 4 - Scenario 01

Human actors (avatars), bins, graffiti, rubbish and litter in Figure 4.15 were obtained from the UE Marketplace to reflect the environmental cues identified in Table 4.2. Unreal Engine 4 can be used as a quick and easy way of displaying scenarios. The Unreal Engine VR framework allows for testing of these different scenarios, concepts, and layouts that can easily be communicated and understood. The Unreal Engine VR framework also provides a rich, unified framework for building such scenarios and simulations. Expanding on Figure 4.15, Figures 4.16 – 4.18 depict environmental cues that were added to the simulation of virtual urban alleyways in this scenario. Next, building on the workflow used for Scenario 01, the next four scenarios (see Table 4.2) were constructed.

Figure 4.16: Environmental cues – bins, rubbish, graffiti, and moving people in the virtual urban alleyway simulation

Figure 4.17: Environmental cues – graffiti, a group of men hanging out, and moving people in the virtual urban alleyway simulation

Figure 4.18: Environmental cues – graffiti and rubbish in the virtual urban alleyway simulation

4.4 Virtual reality simulation testing and implementation

Testing and implementation is the final step of designing the virtual reality simulation. This step tests, validates, and verifies that the virtual reality simulation meets the technical and design requirements, and can be implemented with no-to-minimum risks to the participants, researcher, data, and equipment employed in the VR study. To this end, prior to running a full-scale experiment of the virtual reality simulation, there were two feasibility and usability trials to test its functionality and design i.e., level of immersion and realism, respectively. The first trial tested the functionality of graze tracking, and navigation, including speed, motion and rotation, and data inputs and outputs. For this trial, two participants who are academics in the fields of urban studies and immersive technologies were invited to obtain their expert opinions and feedback. The second stage of the first trial was conducted after refining the simulation based on their feedback as shown in Table 4.3. This stage focused more on the design of alleyways. For example, two women participants from the university, who volunteered to participate and test the simulation, were invited to provide their opinions on how representative the virtual alleyway was of a real-world alleyway i.e., the level of realism. Table 4.3 summarises the participants' feedback from each stage of the first trial.

Four participants assessed the functionality and design against several factors such as navigation, the effect of streetlighting, motion speed i.e., speed of navigation, eye level from first person point of view, and the level of realism. They were also asked to assess the level of comfort based on dizziness (for example, feeling dizzy while using the VR headset i.e., virtual reality-induced symptoms and effects). Moreover, they assessed user-friendly and usability of alleyway simulations, and other relevant technical or design aspects. In response to their feedback, every step was taken to address the issues identified and refine the VR simulations.

Table 4.2: Summary of feedback against testing criteria from the first trial, including two stages

	User 01	User 02	User 03	User 04
Navigation	Not smooth	Smooth	Smooth	Smooth
Effect of street lighting	Good	Good	Good	Good
Motion speed	Not smooth	Fast	Normal	Normal
Eye-level (first person standing view)	High	High	Normal	Normal
Level of realism	Good	Good	Good	Good
Dizziness	Yes	No	No	No
User-friendly	Better with controller instructions	Yes	Yes	Yes
Other technical or design aspects	Unrealistic street light heights	Dead-ends, varied pedestrian behaviour	-Difficult to navigate through a city environment -Focused scenes would be easy to navigate	-Day and night change – automate -Presence of shadows and reflections

Whilst there were only two stages of testing, the VR simulation was being continuously updated based on the trials run by the researcher and the academic supervisor in the field of immersive technologies. There were continuous updates until the simulation was ready for a pilot study. Then, a pilot study was conducted with four participants (young women from the university, aged between 19 -30 years). The aim of the pilot study was to assess the feasibility of a participant completing the simulated alleyway walkthroughs, from start to end, including the survey questionnaire and test the realistic nature of the scenarios. This tested the duration taken to complete all scenarios, which were seven at the time of the pilot study. It was found from the pilot study that the average time taken by a participant to complete the virtual reality experiment was 45 minutes. A participant spent an average of 30 minutes doing the simulated alleyway walkthroughs and 15 minutes completing the follow-up questionnaire survey.

Whilst immersive virtual reality has emerged as a novel tool for neuroscientific and neuropsychological research (Parsons et al., 2018), there are concerns pertinent to implementing virtual reality in research settings. These concerns especially revolve around the head-mounted display (HMD) systems (Palmisano et al., 2017). A primary concern is the presence of adverse physiological symptoms (i.e., nausea, dizziness, disorientation, fatigue, and postural instability), which are referred to as motion-sickness, cybersickness, virtual reality sickness or virtual reality-induced symptoms and effects (VRISE) (Palmisano et al., 2017). These adverse effects have been associated with spending longer durations in a virtual environment (Kourtesis et al., 2019). Existing studies in virtual reality and immersive technologies have also shown that virtual reality-induced symptoms and effects decrease reaction times and overall cognitive performance (Mittelstaedt et al., 2019), which may compromise physiological and cognitive data acquisition. In a recent study, Kourtesis et al. (2019) used a virtual reality neuroscience questionnaire (VRNQ) to investigate the appropriate and maximum duration of virtual reality research and clinical sessions. Their study aimed to alleviate the presence of VRISE. Whilst their findings suggest that a VR implementation with a maximum duration between 50 and 70 minutes is substantially feasible, their work also suggests that VRISE are considerably reduced or prevented by using VR software that facilitates ergonomic navigation (for example, physical movement) and interaction (for example, direct-hand tracking). Considering these factors and the results of the pilot study, it was deemed necessary to reduce the number of scenarios to ensure that participants who had no prior experience with VR, had ample time to familiarise themselves with the technology, immersion, and navigation, and that they were comfortable in completing the virtual reality experiment. This was also key to acquiring accurate and reliable data. Therefore, the number of scenarios was reduced to five, without compromising the conceptual design of alleyways, which is presented in Section 4.3 (see Table 4.1).

Overall, participants agreed after the pilot study that their gaze data from the VR simulation reflected their perceptions of criminal risk when they navigated the simulated alleyways. This was validated against the survey data collected. They also rated the level of realism and user-friendly as 'good' (see Appendix C) on the follow-up survey. These findings from the pilot study reinforce the potential of using VR for exploring momentary and context-specific perceptions of criminal risk as people navigate urban spaces.

4.5 Conclusion

This chapter proposes a novel approach to studying the perception of criminal risk with reference to its momentary and context-specific nature at micro-level urban spaces such as alleyways. Simply put, this approach is an attempt to understand and frame the perception of criminal risk as a dynamic experience lived by people as they navigate these urban spaces. To support this approach, Section 4 describes the design and development process of a novel VR simulation, and how this has been tested not only once, but three times, with continuous updates to the design and functionality to achieve an appropriate level of realism and dynamism within the simulated alleyways. The aim of developing this VR simulation is two-fold: first, to acquire empirical data relating to women's perceptions of criminal risk and its momentary and context-specific variations, and second, to explore the effectiveness of gaze-based VR simulation as a data collection technique.

Furthermore, utilising a game engine such as Unreal Engine 4 can greatly improve the real-time walkthrough experience needed in a virtual reality simulation. This also improves image and video resolution, thereby improving the quality of the scenarios. These can minimise virtual reality-induced symptoms and effects, which in turn, leads to acquiring data with higher accuracy and better quality. Following the design and testing of the VR simulations in this chapter, the next chapter will report the findings generated from the VR study. It will begin with the initial demonstration of the types of data acquired and their interpretations in relation to each alleyway scenario. In doing so, it also aims to augment the theoretical and methodological arguments made in Chapters 2, 3, and 4 respectively.

Chapter 5

The environment and the perception of criminal risk

5.1 Introduction

The perception of criminal risk is a critical aspect of understanding how individuals interact with their environment and make judgements related to their safety and security. The relationship between the environment and the perception of criminal risk is a complex and multifaceted topic that has significant implications for public safety, urban planning, and law enforcement strategies. Academic literature identifies that certain features / cues of the environment, be they social or physical, have an association with the perception of criminal risk (Perkins and Taylor, 1996; Bannister and Fyfe, 2001; Doran and Lees, 2005; Sampson, 2009; Lorenc et al., 2013a; Andrew, 2015; Hinkle, 2015; Solymosi et al., 2018; Taylor and Ralph, 2018). These social and physical cues are indicative of the degree of formal and informal control, for example, where such incivilities are present, they indicate a lack of control to the observer and provoke the perception of criminal risk. Stemming from the prospect-refuge theory (Appleton, 1975), there are also discussions around the relevance of the qualities of the space (design) that have been extended to different urban spaces, including alleyways (Herzog and Flynn-Smith, 2001). Consequently, linking urban design concepts to the prospect-refuge theory, entrapment and permeability in an urban street setting were also considered significant in relation to the perception of criminal risk (Park and Garcia, 2020). Thus, the literature not only identifies that there is an association between the environment and the perception of criminal risk but also identifies the environment as a physical component which comprises a design component and a social component, which is the presence of people who may pose a criminal threat. Nevertheless, the existing attempts fail to measure the significance of these environmental cues and their relation to one another, and the extent to which they are momentary and context-specific. Therefore, this empirical study attempts to explore the momentary and context-specific perception of criminal risk in urban alleyways via a novel methodological and theoretical triangulation.

In response to the existing literature, this chapter presents the data generated by the VR experiment and the follow-up survey. It is structured in the following fashion: Section 5.2 presents the empirical findings and survey findings, each sub-section focusing on the association between environmental design, incivilities, and the perception of criminal risk. Section 5.3 then uses this data to explore the momentary and context-specific nature of the perception of criminal risk, emphasising on the relative significance of these environmental cues as women navigate urban alleyways. Finally, section 5.4 discusses the key findings in relation to existing literature i.e., where this study corroborates existing findings and where it differs or advances the existing literature.

5.2 The association between environmental design, incivilities, and the perception of criminal risk

To understand how people's perception of criminal risk varies dependent on the context and time, it is possible to look at the environmental design and incivilities that are associated with increased levels of criminal risk. This association suggests that the way an environment is designed and the presence of visible signs of incivilities can influence individuals' perceptions of criminal risk. As discussed in Chapter 2, previous studies in this field tend to investigate this association using survey questionnaires as the primary method to acquire people's perceptions of criminal risk. These surveys are inclined to present how people think they would feel if they were to navigate a particular urban space at a particular time of the day, as opposed to how they would perceive such urban spaces in the real world, thus, helping them to calculate potential criminal risk. As such, dynamism as a key variable is included in the urban alleyway scenarios in the virtual environment, which has not been considered in the existing studies. Dynamism in this context speaks not only to the participants' ability to navigate through the virtual urban alleyway, but also to the dynamic environmental cues i.e., the presence of people and their behaviour in the alleyways.

Further, this study brings in gaze dwell time, which is an aspect of behavioural sciences to explore its potential as a measure for assessing an individual's perception of criminal risk. As discussed in Chapters 2 and 3, when people perceive a particular context as potentially risky or criminal, they may exhibit longer gaze dwell times on the environmental cue that they perceive as a risk. Therefore, this section and the next sections serve to explore if it is possible to consider gaze dwell time as part of a broader set of behavioural and contextual cues when assessing criminal risk perception.

Considering the above-explained associations between different variables, including environmental cues and the perception of criminal risk, this section explores the impact of environmental design and incivilities on the perception of criminal risk using the gaze data generated by the VR experiment and ranking data from the survey tool. First, it presents the empirical findings through the VR experiment, focusing on how the participants' perception of criminal risk varies as they navigate urban alleyway scenarios. Secondly, it presents the findings from the follow-up survey questionnaire, which indicates participants' ranking (from 1 to 5, where 1 is no criminal risk and 5 is a very high criminal risk) against these environmental cues. Then, this section ends with a summary of its key findings and a brief direction to the next section.

5.2.1 Empirical findings

Building on the existing fear of crime literature, as well as the environmental design (urban design) concepts linked to the perception of criminal risk, the VR experiment looks at five independent variables and seeks to explore how their presence increases or decreases women's perception of criminal risk when walking through an urban alleyway at different times of the day. Table 5.1 summarises these independent variables and their sub-variables.

Table 5.1: Summary of independent environmental cues (design and incivilities) considered in the study

Independent variable	Sub variable
Visual permeability (End visibility)	
Visual entrapment	
Social (human) presence	A group of men hanging around at the front
	A group of men hanging around at the back
	Moving people
Maintenance	Graffiti
	Rubbish and litter
Street lighting	Well-lit
	Poorly lit

Whilst visual permeability and visual entrapment speak to the design of the urban alleyway, social presence, maintenance, and street lighting represent features of the environment that have been identified as increasing criminal risk in the literature. Previous studies have attempted to investigate the impact of environmental design on people's perception of risk (Cozens and Sun, 2019). Another set of studies has investigated the impact of environmental features (physical and social incivilities) (see Table 5.1) on people's perception of criminal risk (Abed and Aljibarat, 2023; Caridade et al., 2022). It is evident from these studies that there has not been a holistic approach to exploring the impact of both environmental (urban) design and incivilities (physical and social incivilities) in a spatial context at a given moment. With this in mind, this study uses a methodological approach to explore how significant these environmental cues are in relation to women's perception of criminal risk.

This sub-section presents the gaze dwell time data generated by the VR experiment in the form of heat plots and data descriptions. It also describes each scenario in terms of its context i.e., which cues are present, and temporality i.e., daytime or night-time. Each scenario is followed by the presentation of gaze dwell time data and its description.

Scenario 01

Figure 5.1 (see URL for the video in Appendix D) presents a typical urban alleyway (Scenario 01) at the daytime, with all environmental features present, i.e., moving people, groups of men hanging out, graffiti, and rubbish and litter lying around. In relation to the design of the urban alleyway, this has an unobstructed line of sight to the end of the alleyway, which accounts for adequate visual permeability. It also offers a low level of visual entrapment as the alleyway is less confined and has better sightlines with a visible sky. Figure 5.2 illustrates which environmental features, and the design captured the attention of the users (N=30) in terms of where they looked at and for how long were they looking at that feature.

Figure 5.1: View from the point of entry of urban alleyway Scenario 01

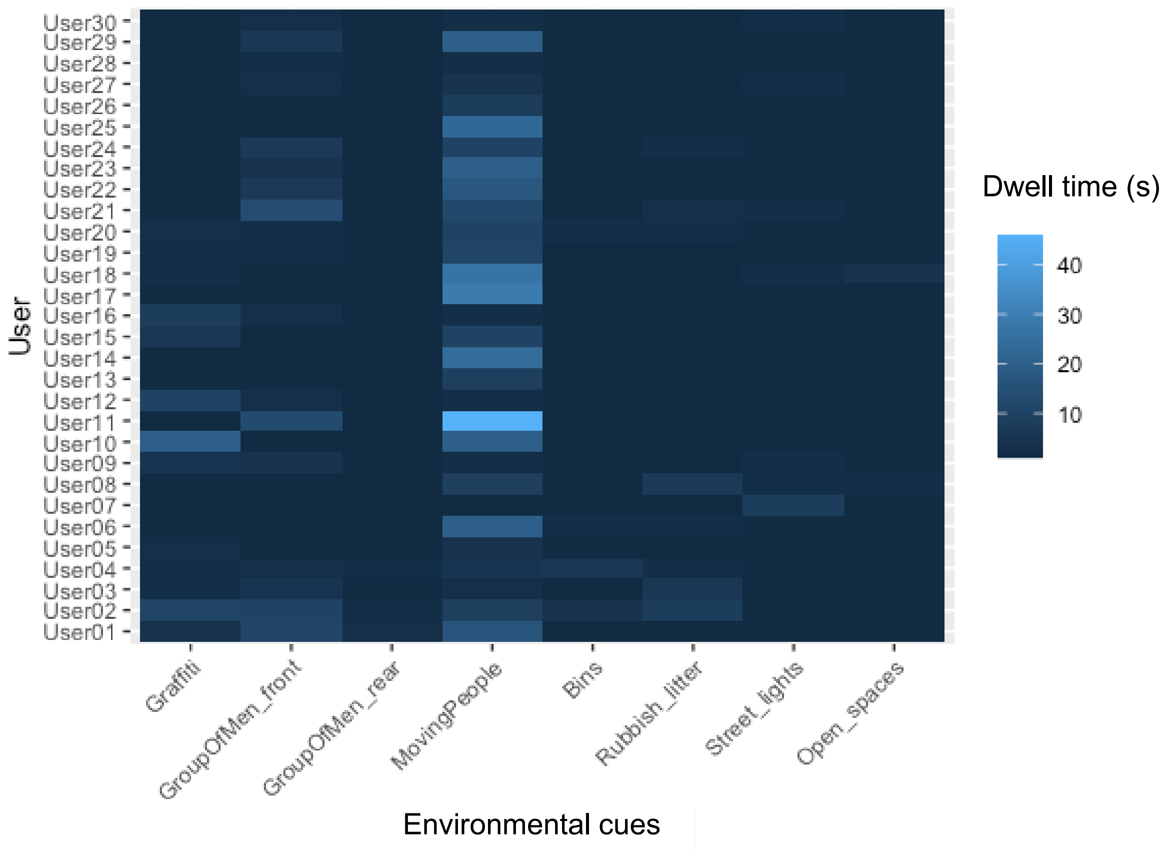


Figure 5.2: Scenario 01 heat plot visualisation of gaze dwell time (s)

This scenario has three social-presence related sub variables – two variables about positioning (e.g: group of men at the front and back) and one variable about dynamism (e.g: moving people). Figure 5.2 presents gaze dwell time data (in seconds) of each participant (Y axis) in relation to the environmental cues (X axis) that were present in scenario 01. The longer the gaze dwell time, the lighter the colour on the heat plot, for example, user 11's gaze dwell time at moving people is relatively higher than the others, thus plotted in light-blue shade. As illustrated in Figure 5.2, moving people have drawn the most visual attention across all users. It is also interesting that there are varying lengths of gaze dwell time about group of men at the front (at the beginning of the alleyway) as opposed to the group of men at the rear (towards the end of the alleyway). In terms of physical incivilities, there is a light interest of graffiti over bins and rubbish, which gives an indication of disorder as opposed to civility.

Scenario 02

Figure 5.3 (see URL for the video in Appendix D presents a tunnelled urban alleyway (Scenario 02) at night, with the environmental features such as moving people, groups of men hanging out at the front, graffiti, and rubbish and litter lying around. In relation to the design of the urban alleyway, this has an obstructed line of sight to the end of the alleyway due its curvature, which makes the alleyway less visually permeable. There is relatively a higher level of visual entrapment as the alleyway is in the form of a tunnel, which makes it confined with no visible sky or open spaces after entering the alleyway. Figure 5.4 illustrates which environmental features captured most attention of the users (N = 30) in terms of where they looked at and for how long were they looking at that feature.

Figure 5.3: View from the point of entry of urban alleyway Scenario 02

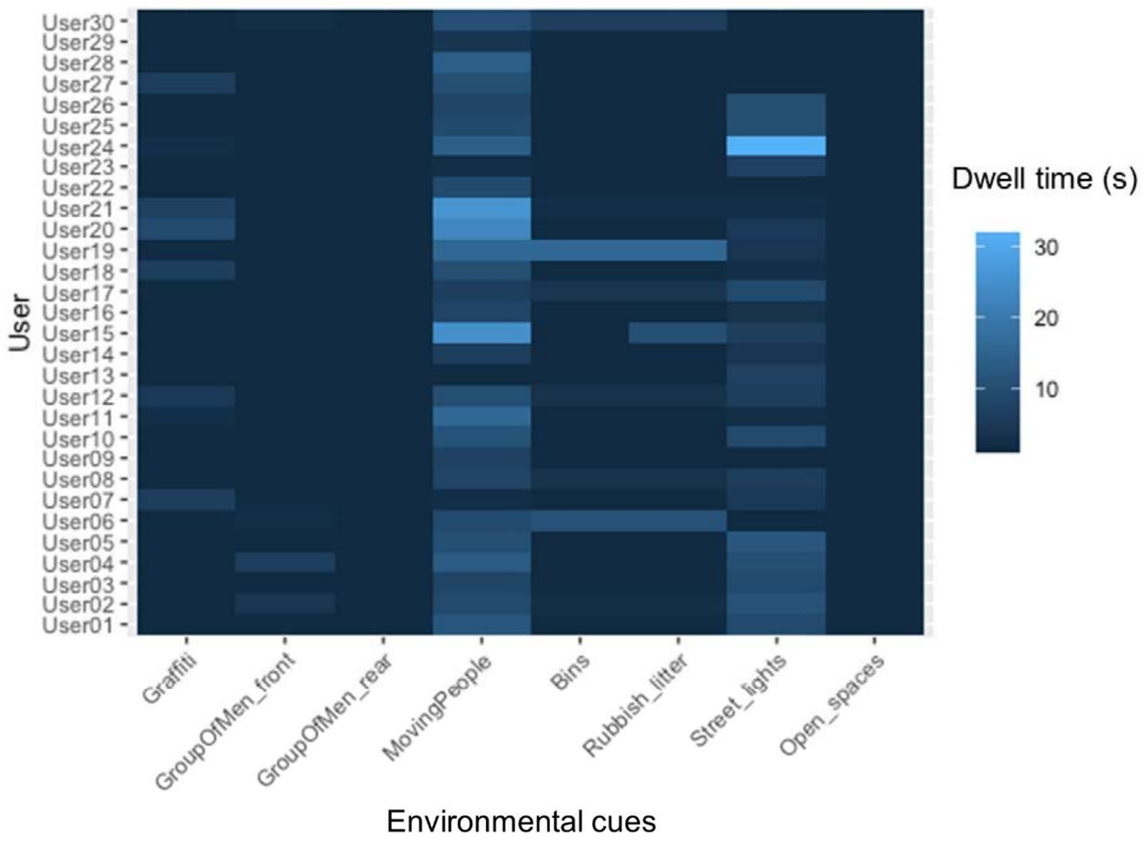


Figure 5.4: Scenario 02 heat plot visualisation of gaze dwell time (s)

As illustrated in Figure 4, moving people and street lighting have captured the most visual attention across all users. Even though lighting is an important aspect of a safe public space, such characteristics often do not come alone. Lighting often interacts with other features of the environment that lead to reduced risk of crime, such as good visual permeability and visibility (Ceccato, 2020). Scenario 02 being a tunnelled alleyway at the night-time can explain the increased interest in street lighting as there is little to no visual permeability as to what to expect after the curvature and when a user exits the tunnel. The only form of light inside the alleyway is from street lighting as the space is both visually and physically enclosed.

Scenario 03

Figure 5.5 (see URL for the video in Appendix D) presents an alleyway as same as Figure 5.1 in relation to its design and environmental features, but poorly lit at the night-time. Figure 5.6 shows that within this scenario, moving people has drawn most visual attention across all users. The group of men hanging out at the beginning of the alleyway and streetlights have captured considerable attention compared with other environmental cues. There is also minimal interest in graffiti.

Figure 5.5: View from the point of entry of urban alleyway Scenario 03

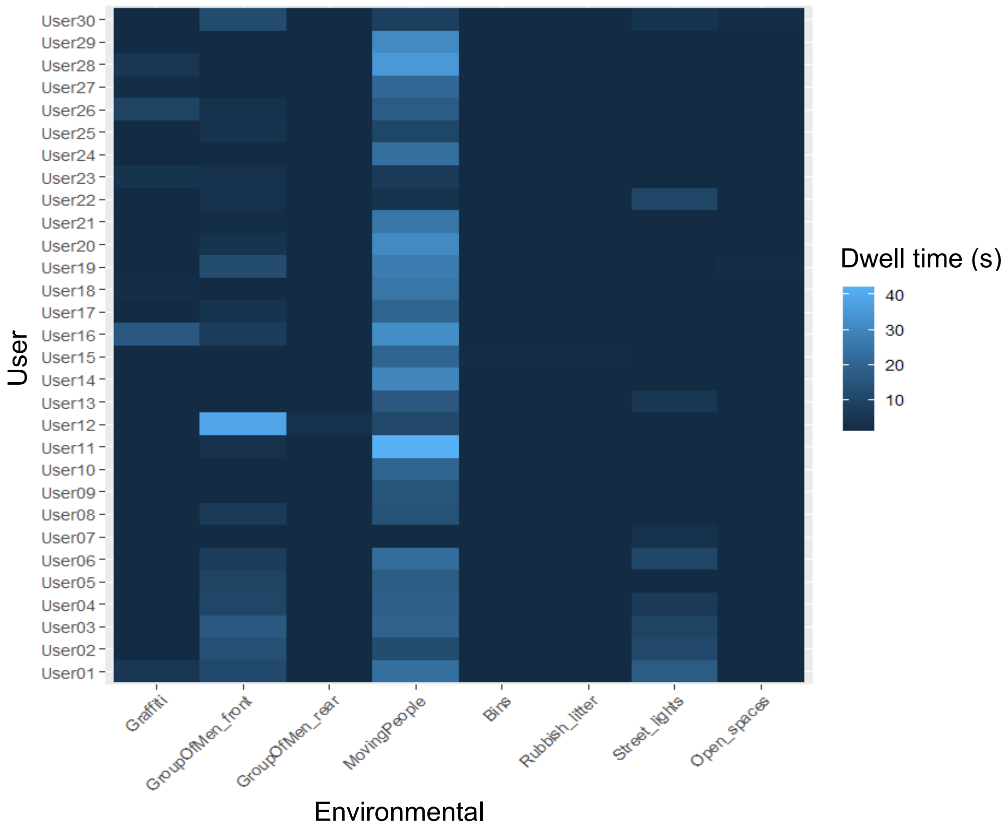


Figure 5.6: Scenario 03 heat plot visualisation of gaze dwell time (s)

Scenario 04

Figure 5.7 (see URL for the video in Appendix D) presents a typical urban alleyway with less social presence, i.e., without moving people at the daytime. Two groups of men hanging out at the beginning and at the end of the alleyway represent social presence and behaviour in this scenario. For other environmental cues, a few bins, and rubbish and litter lying around can be seen along the path. As Figure 5.8 illustrates, the group of men at the front has gained most visual attention, which has, so far, been a consistent finding across Scenarios 01 through 04. Participants have also paid a considerable attention to the group of men at the end of the alleyway in this scenario. Graffiti appears to have captured significant visual attention of most users compared with other environmental cues.

Figure 5.7: View from the point of entry of urban alleyway Scenario 04

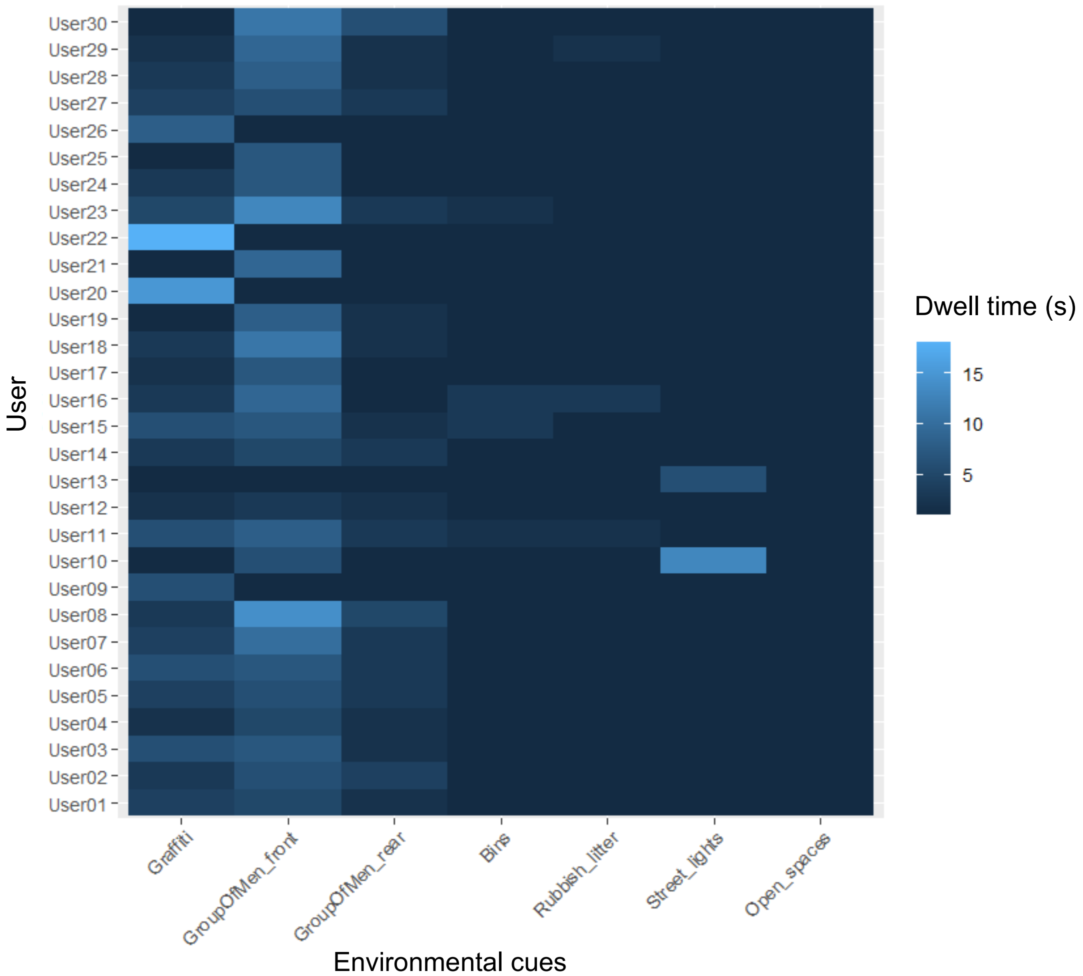


Figure 5.8: Scenario 04 heat plot visualisation of gaze dwell time (s)

Scenario 05

Figure 5.9 (see URL for the video in Appendix D) presents the same alleyway as Figure 7 in terms of its environmental features and the design, but at night-time with a well-lit environment. There are two groups of men hanging out at the beginning and end of the alleyway that represent social presence. There is also graffiti which is a sign of vandalism, and rubbish and litter lying around which is a sign of poor maintenance. Gaze results of this scenario which are shown in Figure 5.10, highlight that most users have avoided looking at these environmental cues as they have spent relatively more time looking at wide open spaces at the beginning and the end of the alleyway. Secondly, the group of men at the beginning and at the end, and streetlights have also captured their visual attention to some extent. Further, there is a slight interest in graffiti, and rubbish and litter lying around the alleyway.

Figure 5.9: View from the point of entry of urban alleyway Scenario 05

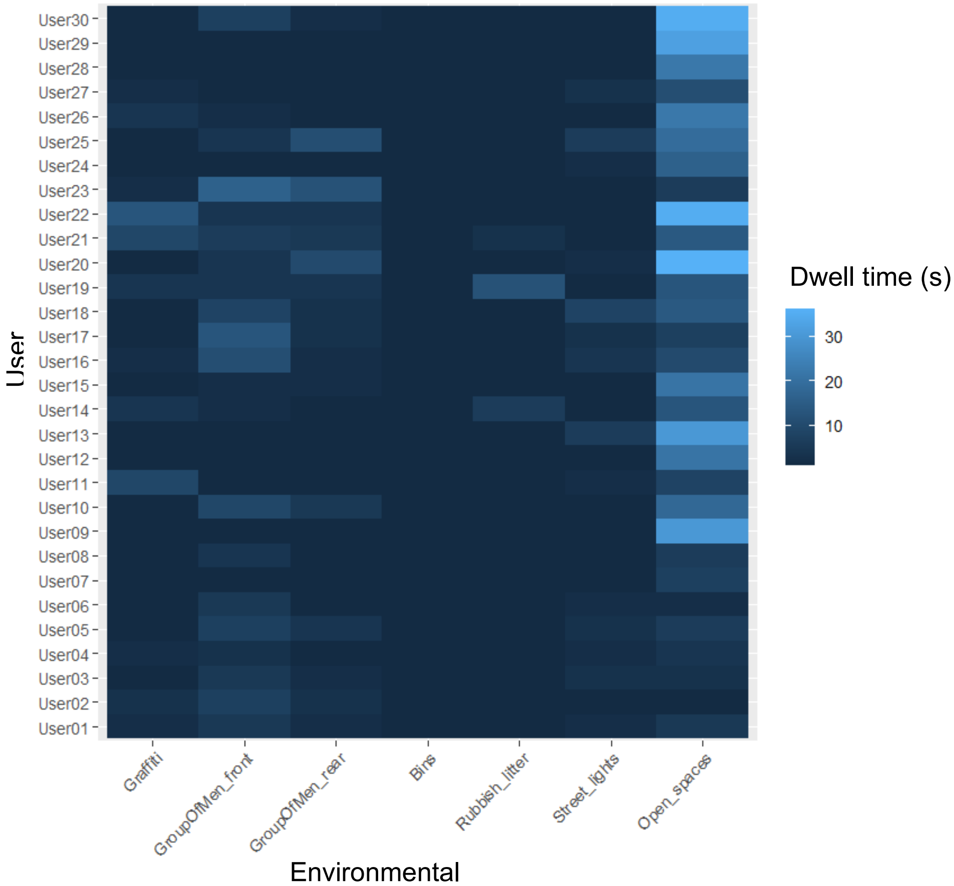


Figure 5.10: Scenario 05 heat plot visualisation of gaze dwell time (s)

5.2.2 Empirical findings: summary of key findings

The findings of the VR study (see Figures 5.2, 5.4, 5.6, 5.8, and 5.10), based on gaze dwell time, suggest that the presence of people, including men hanging out at the beginning and end of an alleyway and moving people, street lighting, and graffiti are relatively more looked at than the other environmental cues. Amongst these cues, the presence of moving people has captured the most visual attention, irrespective of the time of day and the design of the alleyway over other cues (see Figures 5.2, 5.4 and 5.6). In scenarios where there is no presence of moving people, participants' gaze has shifted to the other people variable, which are the groups of men hanging out around the corners of the alleyway and graffiti in the daytime (see Figure 8). At night time, in well-lit alleyway where there is no presence of moving people, participants have been gazing at open spaces along the alleyway significantly (see Figure 10) over the groups of men hanging out around the corners of the alleyway.

Participants' gaze dwell time data also suggest that the group of men at the beginning of the alleyway has captured relatively more visual interest as opposed to the group of men at the end of the alleyway. This finding is consistent across all five scenarios irrespective of the time of day and the design of the alleyway, which indicates a lower threshold amongst the participants for perceived criminal risk, thus, increasing their perception of criminal risk in relation to the group of men hanging out at the beginning of the alleyway. This is because participants are faced with a decision-making point at the beginning of the alleyway as to whether they should enter the alleyway or change the route. This also implies that the position of these environmental cues is also important when investigating the people's perception of criminal risk as they navigate these urban alleyways.

It is also found that street lighting at night-time scenarios is important to the participants to make decisions about their immediate surroundings as they navigate the alleyways. When navigating a well-lit alleyway that presents as a tunnel with visual entrapment and has a curvature, thus providing less visual permeability, participants' gaze data (see Figure 5.4) indicate that most of them have been looking at streetlights as they moved through the alleyway. Similarly, when walking through a poorly lit alleyway with no visual entrapment, they have gazed at streetlights to some extent, though there are other cues that have captured their visual attention over this. On the other hand, when navigating a well-lit alleyway with no visual entrapment and with visual permeability, most of the participants looked at open spaces along the alleyway as they progressed with their walkthrough, and less at the streetlights. Further, there is a slight visual interest in graffiti across all five scenarios, though at varying lengths of gaze dependent on the context of the alleyway and the time of day, over rubbish and litter lying around.

Therefore, the findings of the virtual reality experiment report that the incivilities, both social and physical, are significant to people as measured by their gaze dwell time, which is in line with previous literature references. It also suggests that the environmental design (visual entrapment and visual permeability in this study) can influence what incivilities would capture people's visual attention the most when they navigate these urban alleyways. However, the findings in this section also report that the length of gaze can vary even for the same environmental cue across different scenarios, and such variations can be dependent on the time of day and the context of the alleyway which includes its design, and the position of other environmental cues.

5.2.3 Survey findings

A follow-up survey can be important in an empirical study to corroborate empirical findings for several reasons. Empirical findings can be subject to various biases or limitations. Therefore, a follow-up survey allows to gather additional data to strengthen the validity of the initial findings of this study. By replicating the results through a different method i.e., a survey, it is possible to increase the accuracy of the conclusions. A follow-up survey also helps identify inconsistencies between the empirical findings through gaze data and the survey data. Using a follow-up survey, it is also possible to gain a deeper understanding of an individual's perception of criminal risk through open-ended questions which ask for reasoning for their responses. This qualitative data can complement and corroborate the empirical findings of the study.

The follow-up survey explained in Chapter 3 employs a structured analytic framework aimed at validating the accuracy of VR gaze data by capturing participants' perceptions of criminal risk. Leveraging a mixed-methods approach, the survey begins with demographic enquiries and previous personal victimisation experiences to contextualise responses. Subsequently, participants are presented with a Likert-scale question to rank their perceptions of criminal risk against the environmental cues explained in Section 5.2 through a ranking system from 1 to 5, where 1 is no criminal risk at all and 5 is a very high criminal risk. This is followed by an open-ended question to explore nuanced perspectives and potential discrepancies between their perceived risk (e.g., survey results) and gaze behaviour (e.g., dwell time). Finally, triangulation techniques are utilised to align survey responses with VR gaze data, facilitating comprehensive validation of the VR technology's effectiveness in assessing criminal risk perceptions. The key survey question posed to obtain the level of perception of criminal risk is as follows (see Table 5.2):

‘Walking through an alleyway, how would the presence of following environmental cues increase your perception of criminal risk?’

(1 = no criminal risk (never), 2 = low criminal risk (rarely), 3 = moderate criminal risk (sometimes), 4 = high criminal risk (often), 5 = very high criminal risk (always)

Table 5.2: Question 12 in the follow-up questionnaire (see Appendix C)

Scenario		**Daytime**	**Night**
End visibility (Visual permeability)	Curved alleyway (no end visibility)		
Visual entrapment / visual enclosure	No open sky (tunnel alleyway)		
Human presence / social presence	Teenagers/men in dark clothes/ hoodies hanging around in the alleyway		
	No presence of people		
	People walking through the alleyway		
Maintenance	Vandalism, graffiti or other deliberate damage to properties, walls, or parked vehicles in the alleyway		
	Rubbish or litter lying around		
Street lighting	Poor lighting (little to no street lighting)		

Thus, this sub-section presents the data produced by the follow-up survey and seeks to explore the survey findings in relation to the empirical findings presented in Section 5.2. Figure 5.11 illustrates the percentage of user rankings 1 to 5 (1 being no criminal risk and 5 being a very high criminal risk) against the environmental cues given in Table 5.2, for both daytime and night-time. Whilst the design of the alleyway in terms of visual permeability (less) and visual entrapment (high) do not seem to increase the perception of criminal risk of many users at the daytime, the majority i.e., about 60% and 53% respectively, perceive alleyways with these design features (less visual permeability and high visual entrapment) to be of very high criminal risk after dark. Moreover, having no or less visual permeability proves to increase the perception of criminal risk in an alleyway after dark more than having high visual entrapment/enclosure among young women based on the results of the survey.

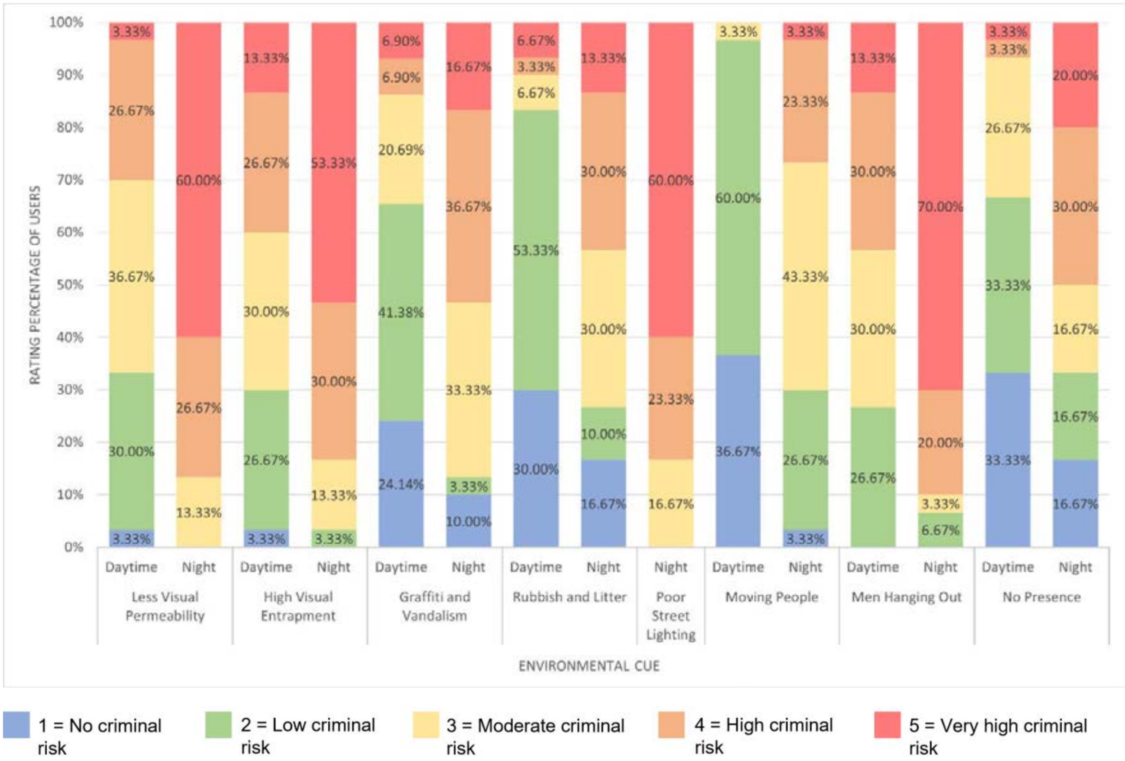


Figure 5.11: User ratings against environmental cues – results from the follow-up survey

More users (about 54%) consider poor maintenance of an alleyway caused by graffiti vandalism to increase their perception of criminal risk from high to very high after dark, whilst only about 14% of the users perceive graffiti and vandalism in an alleyway as a high to very high criminal risk at the daytime. Rubbish and litter lying around in an alleyway as a sign of poor maintenance has a slightly lesser impact on young women's perception of criminal risk at night as opposed to graffiti and vandalism. However, 30% of the users consider rubbish and litter lying around in an alleyway to increase their perception of criminal risk at night (high criminal risk = 4), and 13% of users say that presence of rubbish and litter has a very high impact (high criminal risk = 5) on their perception of criminal risk.

According to survey results (Figure 5.11), poorly lit urban alleyways after dark are perceived to be of very high criminal risk by the majority, which is 60% of the users. 23% of the users consider them to be of high criminal risk, and the rest (17%) of the users consider such an alleyway to be of moderate criminal risk. Past studies suggest that darkness induces a sense of insecurity because it cuts down visibility and recognition at a distance. Dark or dimly lit streets create a limitless source of blind spots, shadows, and potential places of entrapment (Warr, 1990; Painter, 1996; Boomsma and Steg, 2014; Calvillo Cortés and Falcón Morales, 2016). It is also important to note that, based on the survey results, street lighting (poorly lit after dark) and less visual permeability at night are the only environmental cues that have not been ranked lower than 3, which is moderate criminal risk.

It is evident from Figure 5.11 that moving people in an urban alleyway is the only environmental cue that is not perceived as a high or very high criminal risk at the daytime. Majority of the users (60%) consider moving people to be of low criminal risk at the daytime, whilst about 37% of the users perceive them to have no criminal risk at all. After dark, however, 23% of the users perceive moving people to be of high criminal risk (rank = 4) and about 3% of consider it to be very high criminal risk (rank = 5). Majority of the users (43%) view moving people in an alleyway as a moderate criminal risk (rank = 3) at night. On the other hand, groups of men hanging around in the alleyway after dark, irrespective of their location, are perceived as very high criminal risk (rank = 5) by 70% of the users. At the daytime, their perception of criminal risk seems to range between low to very high criminal risk, with 13% ranking as very high criminal risk (rank = 5), 30% of the users ranking as high criminal risk (rank = 4), another 30% ranking as moderate criminal risk (rank = 3), and the rest of 27% ranking as low criminal risk (rank = 2).

5.2.4 Survey findings: summary of key findings

The findings of the follow-up survey suggest that the design of an alleyway has a significant impact on the perception of criminal risk, especially at night-time. For example, over half of the participants associate less visually permeable and more visually entrapped alleyways i.e., curved, and covered alleyways with obstructions to the line sight, with very high criminal risk at night-time. Between permeability and entrapment, the former is considered to have a higher impact on the perception of criminal risk than the latter at night time. At the daytime, level of perceived criminal risk of a less visually permeable and more visually entrapped alleyway seem to vary from low to high criminal risk among the majority of the participants (see Figure 5.11). Whilst only 3% of them associate less visual permeability with very high criminal risk at the daytime, about 13% of the participants find more visually entrapped alleyways to be of very high criminal risk at the daytime.

Secondly, physical incivilities such as graffiti and vandalism, and rubbish and litter lying around are perceived as low to no criminal risk at the daytime by most of the participants. On the contrary, most of the participants associate such physical incivilities with moderate to high criminal risk at night-time. It is also noteworthy that more participants perceive such incivilities as very high criminal risk at night-time as opposed to the daytime. Further, social incivilities such as men hanging out around the corners of alleyways have a more negative impact on the perception of criminal risk, both day and night-time, as opposed to physical incivilities. Whilst most of the participants associate men hanging out around alleyway corners with low to high criminal risk at the daytime, this is perceived as a very high criminal risk at night-time by the majority of the participants. It is also important to report that none of the participants consider men hanging out around alleyways to not be a criminal risk irrespective of the time of day, hence, emphasising that such a social incivility would always be perceived as a risk, but varying levels, be it daytime or night-time.

Although not incivilities, pedestrians i.e., moving people, and no social presence are two other variables related to people that have a significant impact on the participants' perception of criminal risk according to survey results. For example, most of the participants perceive moving people to be of moderate criminal risk at night-time whilst an alleyway with no social presence at night-time is considered high to very high criminal risk by most of them. Survey findings also indicate that none of the participants associate moving people with high or very criminal risk at the daytime as most of them perceive this to be of low criminal risk. Similarly, an alleyway with no social presence is considered as moderate to no criminal risk by most of the participants.

Additionally, survey findings suggest that poor street lighting has a relatively higher impact on participants' perception of criminal risk. Their perceptions vary from moderate to very high criminal risk and none of them perceive poor street lighting at night-time to be either low or no criminal risk. Whilst their perceptions vary from moderate to very high criminal risk, most of them, which is about 60% consider poor street lighting as a very high criminal risk (see Figure 5.11), especially when navigating an alleyway.

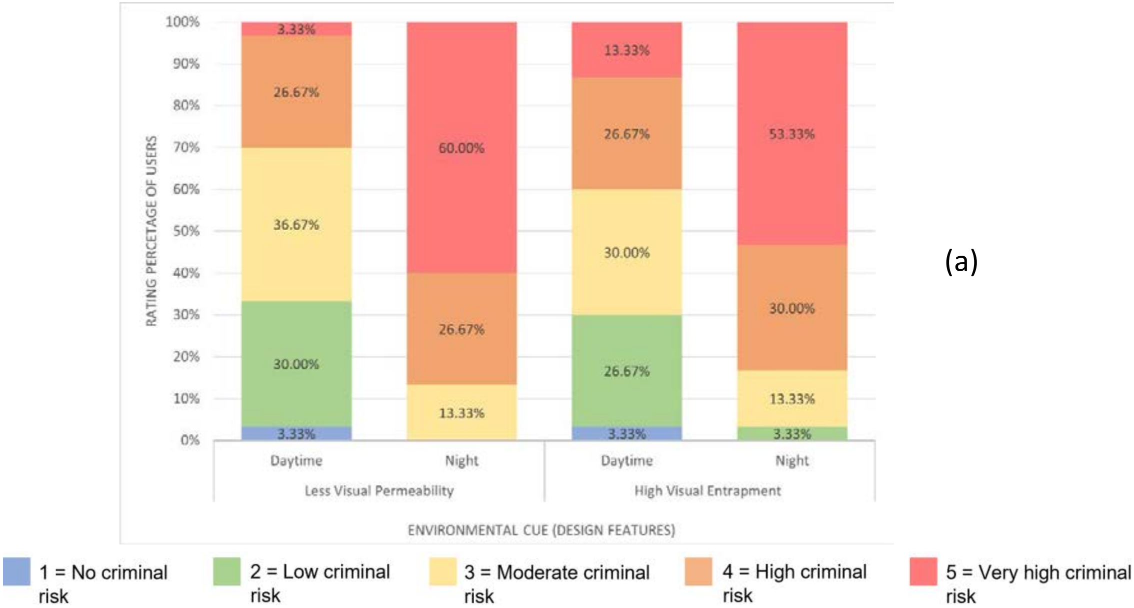
Finally, it is evident that there are similarities between the empirical findings and survey findings when determining the association between environmental design, incivilities, and the perception of criminal risk. Further, by introducing a follow-up survey to the virtual reality experimental study, it has been made possible to corroborate the findings from both these data sources. Whilst the empirical findings accord with survey findings in determining which environmental cues are significant in calculating risk when navigating an urban alleyway, the former also suggests that the significance of these cues can vary contextually and momentarily as and when people navigate an urban alleyway. Therefore, the next section attempts to explore the relative significance of these environmental cues at different moments and contexts.

5.3 The momentary and context-specific nature of the perception of criminal risk

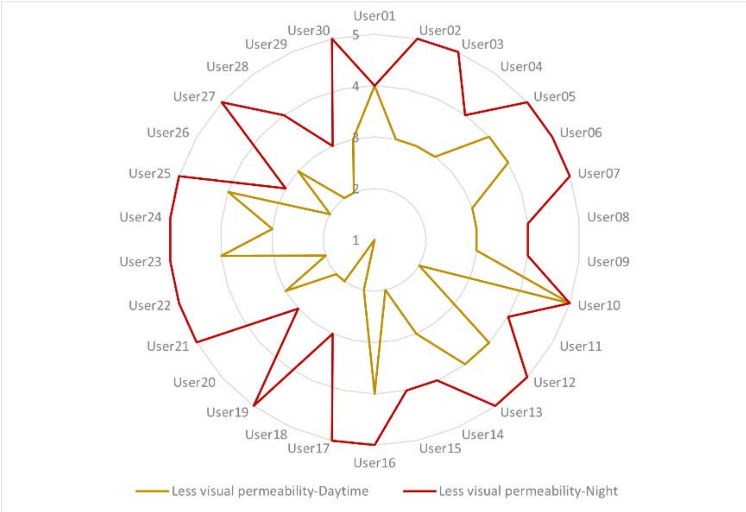
Empirical findings in Section 5.2 indicate that the significance of dynamism and change within a scenario stand out as opposed to static environmental cues. If we are looking at the environmental cues and which cues are important, and where and when they are important, there are two dimensions to this: first dimension is asking 'are these cues in the environment relevant or significant?', which is discussed in section 5.2. Second dimension asks, 'what is their relation to one another?', which speaks to the momentary and context specific nature of the perception of criminal of risk and how this changes as and when people navigate an urban alleyway or other urban spaces. Building on findings from the previous section, this section explores the second dimension i.e., the relative significance of the environmental cues, including both environmental design and incivilities, in people calculating criminal risk in an urban alleyway.

5.3.1 Relative significance: spatial and temporal

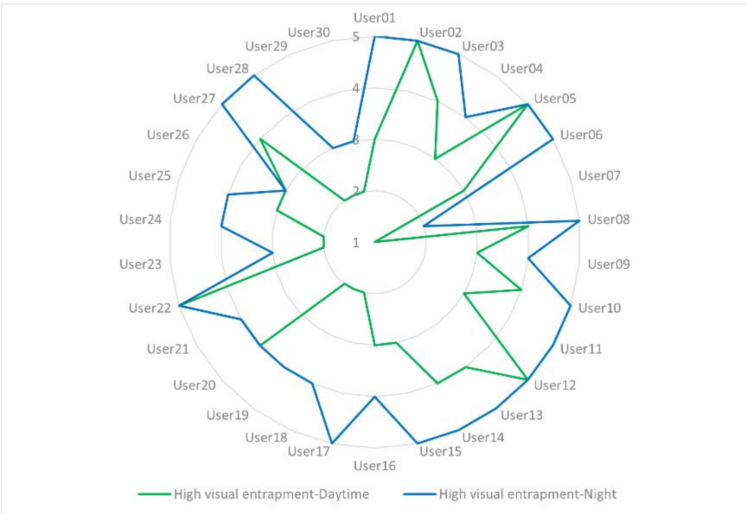
As discussed in section 5.2, moving people, men hanging around the corners of the alleyway, and street lighting are the most considered environmental cues by participants when determining the potential risk for crime in an alleyway. Empirical findings of this study also suggest that the impact of each of these environmental cues on a person's perception of criminal risk is dependent on several factors at a given moment. One factor is the design or context of the environment (of an alleyway in this study), which also include what and where other cues are present. This speaks to the spatial dimension of their perceptions. Another factor is the time, which not only represents the time of day for their perceptions of criminal risk cannot be generalised in to just two categories as daytime and night-time perceptions, but also the momentary nature of their perceptions as and when they navigate urban spaces. This speaks to the temporal dimension of their perceptions.



(a)



(b)



(c)

Figure 5.12: (a) User ratings (percentages) against environmental cues in relation to the design of the urban alleyway; (b) User ratings for less visual permeability daytime and night; (c)User ratings for high visual entrapment/enclosure daytime and night – results from the follow-up survey

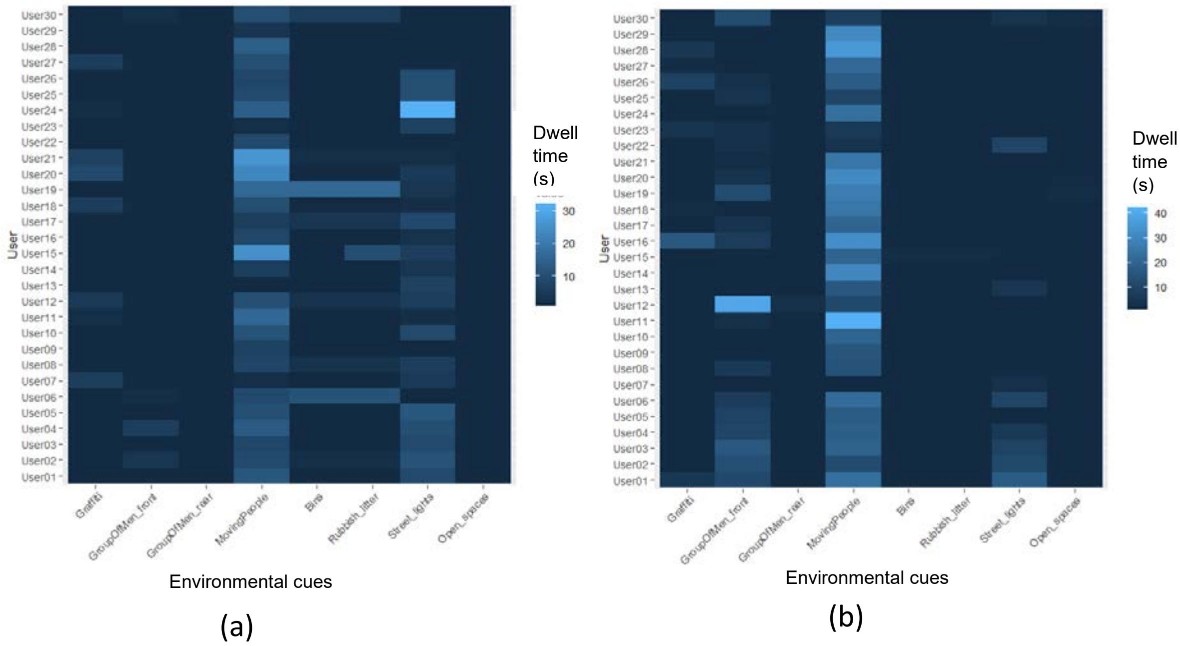
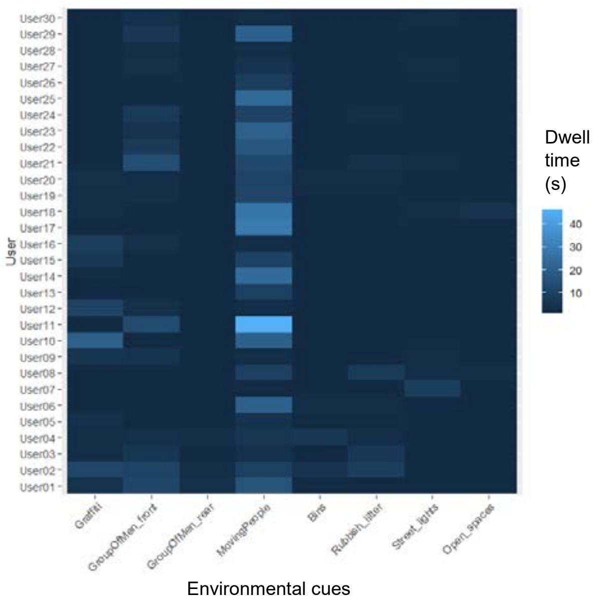


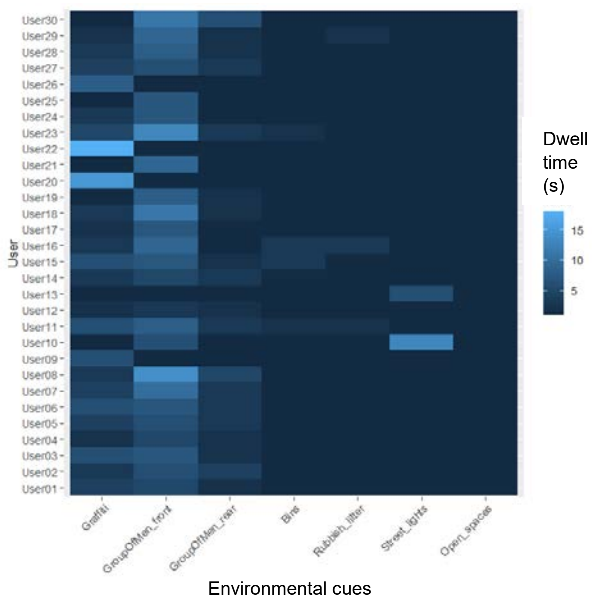
Figure 5.13: Gaze dwell time against environmental cues in (a) Scenario 02 and (b) Scenario 03

It is evident from survey results as depicted in Figure 5.12(a), (b), and (c) that an alleyway with less visual permeability and high visual entrapment/enclosure is more likely to increase people's perception of criminal risk at night as opposed to daytime. Gaze data of Scenario 02, which is representative of a less visually permeable and highly visually enclosed well-lit alleyway at night suggests when other cues are also present in such a context and time, moving people are relatively more looked at than other environmental cues (see Figure 5.13(a)). Streetlights are the second most looked-at cue in this context. Moreover, when an alleyway at night is not visually enclosed but limits visual permeability because of poor lighting as scenario 03 represents, moving people would still gain a relatively higher visual attention (see Figure 5.13(b)) amongst other environmental cues. However, as Figure 5.13(b) shows, the group of men at the beginning of the alleyway becomes the second most looked-at cue in scenario 03 and streetlights become less looked-at. This further complements the importance of dynamism in people calculating various potential criminal risks in urban alleyways that was discussed in section 5.2.3.

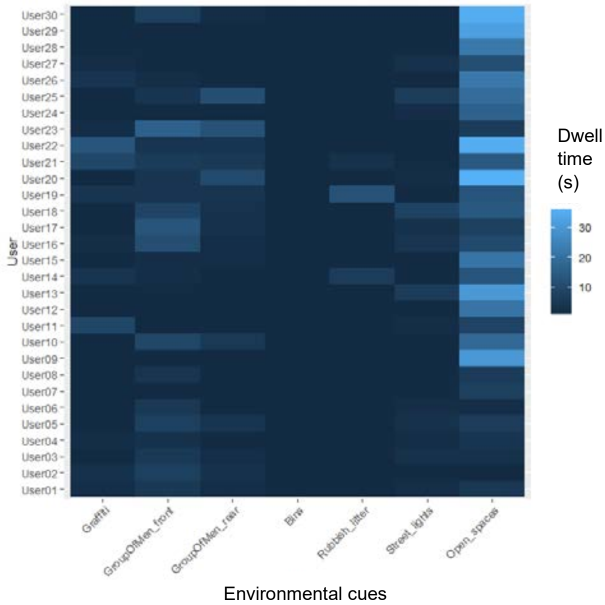
Figures 5.14(a) and 5.14(b) illustrate variations in gaze dwell time between scenarios 01 and 04, which are two daytime scenarios with good visual permeability and without visual entrapment/enclosure. Whilst all other environmental cues remain constant in both scenarios, Figures 5.14(b) and 5.14(c) depict how the absence of moving people has caused users to pay attention to the group of men at the end of the alleyway irrespective of the time of day. As shown in Figure 5.14(b), there are also varying lengths of gaze dwell time between the two groups of men, for example, the group of men at the start of the alleyway seems to be relatively more looked at than the group of men at the end of the alleyway. This suggests that the position of environmental cues, especially the dynamic cues along an alleyway have a direct impact on variations in the perceptions of criminal risk. Such variations have been difficult to capture through traditional methods (Solymosi et al., 2015; Chataway et al., 2017; Crosby and Hermens, 2018; Engström and Kronkvist, 2018; Solymosi et al., 2021).



(a)



(b)



(c)

Figure 5.14: (a) Gaze dwell time against environmental cues in Scenario 01 daytime; (b) Gaze dwell time against environmental cues in Scenario 04 daytime; (c) Gaze dwell time against environmental cues in Scenario 05 night-time

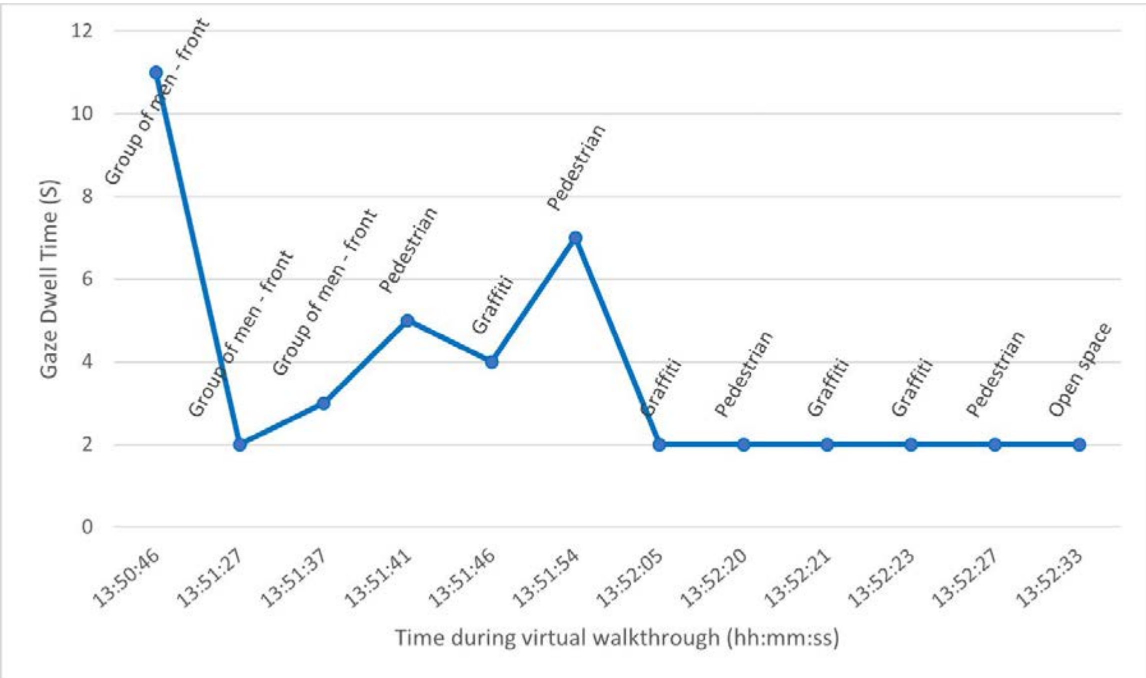


Figure 5.15: A virtual walking trajectory of an individual user for Scenario 01 (daytime) – from start to end of virtual walkthrough

Whilst positioning of environmental cues relates to context-specific nature i.e., spatial dimension of perceptions of criminal risk, there is also an indication of how such positioning may relate to the momentary nature of these perceptions. For example, as Figures 5.14(b) and 5.14(c) illustrate, the length of gaze dwell time at the group of men at the end of alleyway decreases as and when users reach the end of the alleyway. This suggests that variations in the perception of criminal risk are not only dependent on context and time of day i.e., daytime and night, but also on each moment that a person experiences as and when they navigate an urban space. Figure 5.15 is an example from the VR study, indicating how an individual's gaze behaviour changes at each given point of time as they move through the alleyway. Thus, empirical findings of this study indicate how our interpretation of criminal risk can be dynamic as one moves through space, for example, different cues are important as one moves through, and this can be defined as the momentary nature of the perception of criminal risk.

At the same time space and time play an important role in determining the relative significance of the environmental cues in relation to the perception of criminal risk, there are other factors that could contribute to varying levels of criminal risk when people navigate not only urban alleyways, but also other urban spaces.

5.3.2 Relative significance: narratives from survey findings

Empirical findings in Sections 5.2 and 5.3.1 discuss how the presence of dynamic social behaviour, for example, moving people and groups of men hanging around the corners of the alleyways, is perceived to be the most considered environmental cue in this sample of young women when calculating potential criminal risks as they move through the alleyways. The relationship between gender and perception of criminal risk has interested social scientists for decades. During this time, several empirically based explanations have emerged within the literature to explain why gender differences are often observed in fear of crime. For example, Jackson (2009) found that perceptions of risk differ among men and women when considering the social-psychological characteristics of risk (e.g., likelihood of victimisation, consequences of victimisation, and control over crime).

One of the most consistent findings in fear of crime studies is that women are more fearful of crime (Johansson and Haandrikman, 2023), resulting in them avoiding certain places and situations that they perceive to be high criminal risk (Boomsma and Steg, 2014). Survey findings of the present study as illustrated in Figure 5.16, point towards how likely are this sample of young women to use an urban alleyway to get from one place to another. Whilst 60% of the participants would use an alleyway in their everyday life, half of them (50% of who have said 'yes') have certain conditions attached to their response. For example, they will use an alleyway only if they must, and that also only during the day depending on the context. Further, Chataway and Hart (2019) found that the association between gender and victimisation worry is dependent on crime type. Figure 5.17 shows different types of crime risks that participants were concerned about in an alleyway in response to the following question on the follow-up questionnaire.

"What type of crime risks would you be concerned about in an alleyway?"

Being mugged and robbed	
Physical attack	
Sexual assault	
Other	

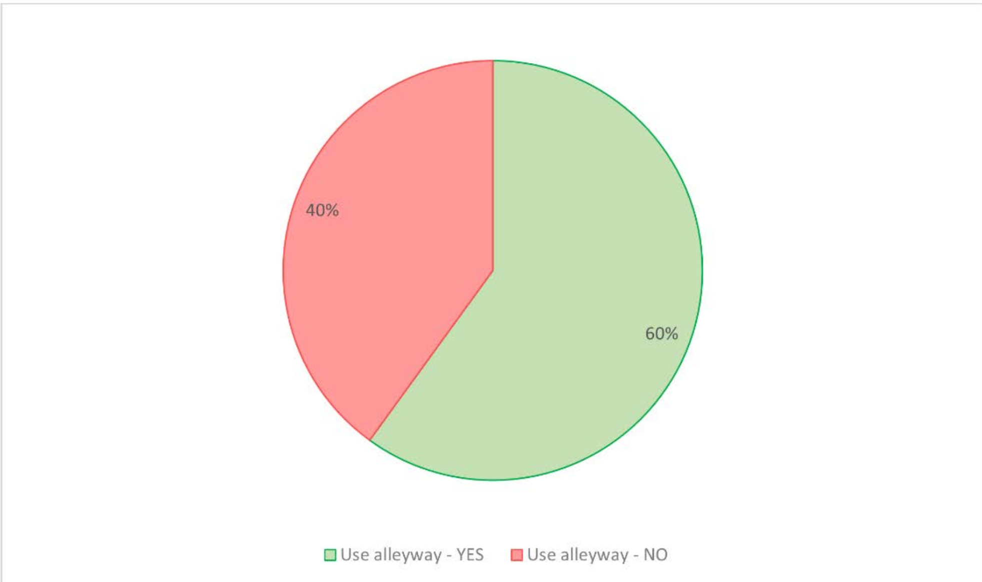


Figure 5.16: Percentage of young women (sample) who would typically use an alleyway to get from one place to another

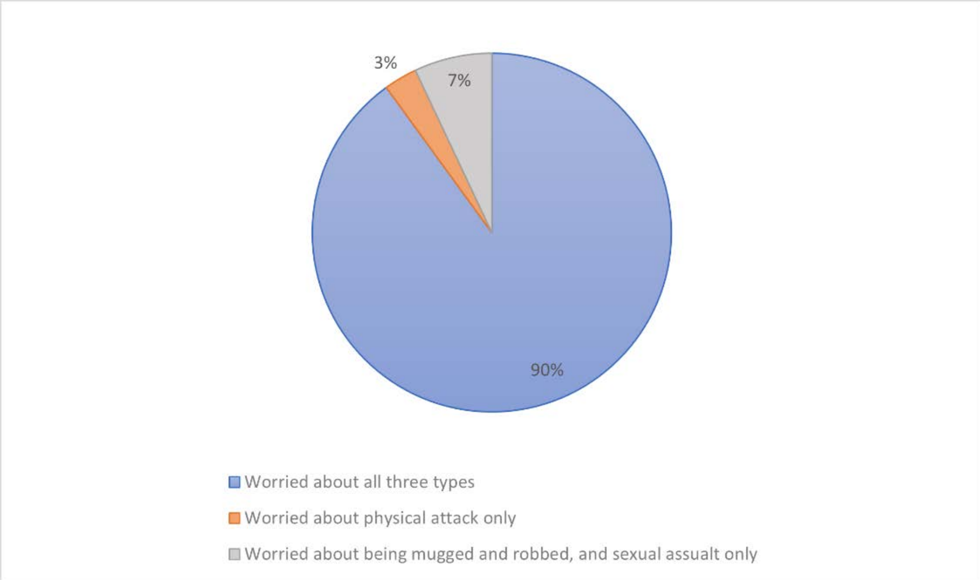


Figure 5.17: Types of crime risks the sample of young women were concerned about in an alleyway

According to Figure 5.17, most of the participants (90%) are concerned about all three types of crime risks – being mugged and robbed, physical attack, and sexual assault. Koskela and Pain (2000) suggest that women's reasons for feeling fearful are not necessarily rooted in the perceived risk of victimisation from what is perceived as criminal activity in one's neighbourhood or immediate environment. However, Johansson and Haandrikman (2023) state that even though women's perception of criminal risk was less impacted by what they perceived as "criminal activity," women who perceived their surrounding environment to be prone to human behaviour-related disorder were more fearful than men. For example, alleyways are often avoided especially by women for this reason (Wang and Taylor, 2006). Features treated by Fisher and Nasar (1992) as indicative of refuge or concealment and thus fear inspiring have been interpreted as indicators of mystery, which can be related to urban alleyways (Herzog and Flynn-Smith, 2001).

Survey findings also demonstrate that the participants' reasons for avoiding using an alleyway to get to one place from another (see Figure 5.16) and the types of criminal risks they are concerned about when navigating an alleyway (see Figure 5.17) are reflective of their gaze behaviour (e.g.: gaze length and direction) discussed in Sections 5.2.1 and 5.3.1. For example, dynamic social behaviour significantly increases their perception of criminal risk when walking through an alleyway, thus, influencing their decision to walk through such an alleyway. It also explains the prolonged gaze dwell times (see sections 5.2.1 and 5.3.1) on moving people irrespective of the time of day.

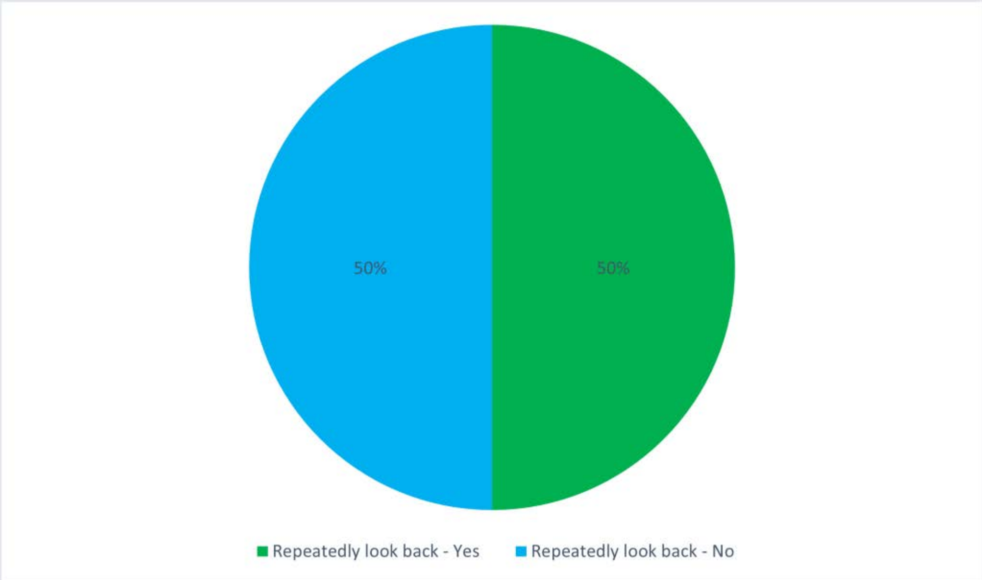


Figure 5.18: Percentage of young women (sample) who would repeatedly look at an environmental cue in real life as opposed to in a virtual environment

Table 5.3: Further explanations by participants to Figure 5.18

Repeatedly look – YES	Repeatedly look – NO
To be cautious of the surrounding	Would keep moving as fast as possible without engaging eye contact
Would look only if walking alone	Would not want anyone to perceive my behaviour as provoking
To be alert and to ensure safety	No eye contact feels safe
To avoid any surprises and shocks	Fear looking directly would result in physical attack
To observe certain people's behaviour and decide whether to walk faster or change direction	Would not want anyone to perceive my behaviour as being scared
To check if someone is watching	Afraid of being a target

Additionally, according to Figure 5.18, 50% of the participants state that they would repeatedly look at an environmental cue in real life as opposed to in a virtual environment, which is an indication of surveillance (Peeters and Vander Beken, 2017). This aligns with participants' explanations listed in Table 5.3 as to why they would or would not repeatedly look at an environmental cue when walking through an alleyway in real life. It is also evident that they would repeatedly look at the dynamic social behaviour as opposed to static environmental cues when calculating criminal risk.

5.4 Discussion

Overall, whilst the findings of this study are based on a small sample, they serve as detailed illustrations and proof of concept for this approach of utilising new methods and triangulation. Therefore, the findings serve as the impetus to further work examining the perceptions of criminal risk as well as urban planning and design. In promoting the exploration and collection of such novel momentary and context-specific data on people's perceptions of criminal risk, this approach can provide a template for generating new perspectives on perceived criminal risk.

Sections 5.2 and 5.3 of this chapter present the findings from the VR study and the follow-up questionnaire which gathered participants' gaze data when navigating urban alleyways and the perception of criminal risk rankings respectively. Results from this study demonstrate that women's perception of criminal risk varies momentarily in relation to the environmental cues (for example, environmental design and incivilities) as and when they navigate urban alleyways. Therefore, through theoretical and novel methodological triangulation, this approach provides a way to explore the momentary and context-specific nature of the perception of criminal risk in relation to the environment.

Empirical findings suggest that incivilities considered in this study, both physical and social, are in fact significant in people calculating criminal risk in an alleyway, which is in line with the previous literature (Nasar and Fisher, 1993; Warr, 1990; Lorenc et al., 2012; Farrington and Welsh, 2007; Boomsma and Steg, 2014; Foster et al., 2010;

Solymosi et al., 2015; Solymosi et al., 2021). One interesting empirical finding, however, is that young women perceive dynamic social behaviour to pose a greater criminal risk than static environmental cues, irrespective of the time of day. For example, moving people i.e., pedestrians have captured the visual attention of most of the participants across all scenarios where they were present. Similarly, men hanging out at the beginning of the alleyway have captured significant visual attention, irrespective of the time of day. This finding, in turn, echoes the dynamic and momentary nature of the perception of criminal risk as people move through urban spaces.

Survey findings of this study demonstrate that when considered individually, these environmental cues (both environmental design and incivilities), including moving people as represented by social presence, and poor street lighting increase young women's perception of criminal risk to a greater extent. However, the empirical findings indicate that whilst these cues are significant, their level of significance varies when these cues are presented together and not individually. This can be dependent on several factors, for example, the design of the alleyway, the presence and position of other cues, and the time of day which have been explored in this study. Therefore, the ability to explore what environmental cues people pay more visual attention to over and above other cues across space and time i.e., their relative significance is a key advance to understanding the association between environment, incivilities, and the perception of criminal risk.

However, there can also be other factors beyond the spatial and temporal dimension, which may be important to consider when investigating the relative significance of environmental cues in people calculating criminal risk. For example, demographic characteristics such as age, gender, ethnic origin, religion, socio-economic status, and people's previous experience in relation to crime and criminal risk may also contribute to the level of significance of these environmental cues in calculating criminal risk as and when they navigate urban spaces. As such, a social dimension should also be explored alongside the spatial and temporal dimensions for a more holistic view of the perception of criminal risk. Therefore, the findings of this study also indicate that, whilst there are perceptions that are common across the sample of young women, there are also differences in the level of their perception of criminal risk, which suggests that people are different, and not everyone is the same.

In relation to measuring the perception of criminal risk, traditional survey-based methods have been criticised for failing to capture the behavioural component in calculating criminal risk (Ferraro and Grange, 1987; Gabriel and Greve, 2003). In response to fear of crime, citizens may adopt 'functional' protective behaviours, but also 'dysfunctional' avoidance behaviours, which are rarely captured by questionnaire-based measures (Jackson and Gray, 2010). By using virtual reality to create a platform where people can experience a walkthrough in alleyways through immersion, this study attempts to overcome such shortcomings of traditional survey-based methods. Moreover, by approaching the same concept of perception of criminal risk and the two research questions with two different tools – a virtual reality experiment and a follow-up survey tool, this study also attempts to reduce bias that comes from using a single method or data source and enhance the validity of the findings. Thus, another potential contribution of this study is that the virtual reality experiment explored the gaze behaviour of people, and through methodological triangulation, as survey findings corroborate empirical findings, it was evident that the gaze is relevant for exploring the perceptions of criminal risk. Therefore, these findings also open a novel discussion around the question 'Is it that which we spend the most time looking at, that has a clearer association with the perceptions of criminal risk?'

Overall, this chapter looks at the association between environment, incivilities, and the perception of criminal risk using two approaches – a virtual reality experiment to capture gaze data and a follow-up survey tool. In doing so, this study not only identifies the extent to which these findings corroborate existing literature in relation to the impact of environment and incivilities on the perception of criminal risk but also advances our understanding of the association between the environment and the perception of criminal risk in relation to the relative significance of environmental cues as and when people navigate urban spaces. However, the task remains to explore whether people's gaze, for example, duration and direction, is reflective of their perception of criminal risk and to understand whether gaze can be used as a potential measure of the perception of criminal risk. To this end, the next chapter explores the association between people's gaze and their perception of criminal risk, triangulating data from the VR study and the follow-up survey.

Chapter 6

Gaze as a measure of the perception of criminal risk and the efficacy of virtual reality

6.1 Introduction

The perception of criminal risk plays a pivotal role in shaping individuals' behaviour and decision-making processes. Understanding how people perceive and assess potential threats within their environment is crucial for developing effective crime prevention strategies and enhancing public safety (Bennett, 2018). However, conventional methods of studying criminal risk perception often lack the capability to capture the intricate cognitive processes underlying risk assessment. On the other hand, the analysis of gaze behaviour, which encompasses the intricate patterns of eye movements, offers a novel and insightful approach to understanding how individuals process and prioritise information within their surroundings (Hayhoe, 2017). Consequently, gaze behaviour serves as a reliable indicator of attention allocation and cognitive processing, offering valuable insights into individuals' visual attention and decision-making processes.

Moreover, recent advancements in technology, particularly the integration of VR, have paved the way for exploring human behaviour in simulated environments that closely mirror real-world scenarios (Cummings and Bailenson, 2016). VR technology allows for the creation of controlled and immersive settings, offering a unique opportunity to investigate individuals' responses to varying levels of perceived criminal risk without subjecting them to actual danger. Therefore, by combining these two approaches, it is possible to track participants' gaze patterns, including duration and direction, whilst they navigate virtual alleyways that present scenarios with varying levels of criminal risk as explained in Chapter 5, Section 5.2.

In response to the existing literature, this chapter aims to explore the potential synergies between the use of gaze behaviour as a measure of the perception of criminal risk and the efficacy of VR technology in creating immersive environments for studying human-environment interactions and behaviour. It is structured in the following fashion: Section 6.2 compares empirical findings against survey findings for triangulation, focusing on understanding whether people's gaze direction and duration are reflective of their perception of criminal risk. Section 6.3 then explores the effectiveness of virtual reality as a data collection technique for similar studies, emphasising on immersion, realistic representations of the real-world, and people's comfort and sensitivity to using VR. Finally, section 6.4 discusses the key findings in relation to existing literature, including differences and advances to existing literature. It also discusses the extent to which the findings of VR experiments are robust through their comparison to the findings from a survey tool.

6.2 The association between gaze and the perception of criminal risk

The influence of visual cues on the perception of criminal risk has garnered significant attention within the domains of urban studies, criminology, psychology, and behavioural sciences. Recent studies have begun to uncover the intricate relationship between gaze behaviour and the subjective assessment of criminal risk. As individuals navigate urban spaces, their visual attention often reflects underlying cognitive processes that shape the interpretation of potential threats or deviant behaviour. Thus, gaze behaviour, which refers to the pattern of eye movements, can provide valuable insights into how individuals process information and assess their environment.

This study brings in gaze dwell time, including gaze duration and direction, which is an aspect of behavioural sciences to explore its potential as a measure for assessing an individual's perception of criminal risk. As discussed in Chapters 2 and 3, when people perceive a particular context as potentially risky or criminal, they may exhibit longer gaze dwell times on the environmental cue that they perceive as a risk. Therefore, considering the above-explained insights into the complex interplay between visual attention and the attribution of criminality, this section serves to explore the possibility of using gaze dwell time as part of a broader set of behavioural and contextual cues when assessing criminal risk perception. First, it presents a comparison between the empirical findings i.e., gaze dwell data generated by the virtual reality experiment and the survey findings, which indicate participants' ranking (from 1 to 5, where 1 is no criminal risk and 5 is very high criminal risk) against these environmental cues. Then, the section ends with a summary of its key findings, focusing on the association between gaze behaviour and the perception of criminal risk, and a brief direction to the next section, which speaks to the efficacy of VR as tool to collect momentary and context-specific perceptions of criminal risk.

6.2.1 Empirical findings vs survey findings

To explore the association between gaze behaviour and the perception of criminal risk, it is possible to compare participants' rankings from the follow-up survey questionnaire (see Section 5.2.3) against gaze dwell time data (see Section 5.2.1). As mentioned above and in Section 5.2.2, participants ranked these cues on a scale from 1 to 5, with 1 being no criminal risk at all to 5 being a very high criminal risk based on the following question in the follow-up survey questionnaire:

'Walking through an alleyway, how would the presence of following environmental cues increase your perception of criminal risk?'

(1 = no criminal risk (never), 2 = low criminal risk (rarely), 3 = moderate criminal risk (sometimes), 4 = high criminal risk (often), 5 = very high criminal risk (always)

Figure 6.1 plots participants' rankings against the previously identified environmental cues for the daytime. In the VR experimental study, Scenarios 01 and 04 represent an urban alleyway at the daytime, which, as shown in Figures 5.2 and 5.8 respectively (see Section 5.2.1), highlight moving people, the group of men hanging out at the beginning and end of the alleyway, and graffiti have drawn most visual attention across all participants. Survey findings are pointing towards a similar pattern where groups of men hanging out, moving people and graffiti seem to pose a greater sense of personal criminal risk as opposed to other cues. Further, survey findings also suggest that when there is no social presence i.e., when people are not present in an alleyway, this may pose as a low to moderate criminal risk to most of the participants (also see Figure 5.11 in Section 5.2.3).

Survey results for night-time, as shown in Figure 6.3, suggest that groups of men hanging out in urban alleyways and poor lighting are the most significant in increasing the participants' perception of criminal risk. Gaze dwell times in scenarios 03 (Figure 6.4 (b)) and 05 (Figure 6.4 (c)) support this survey finding as the group of men at the beginning of the alleyway in both scenarios has gained considerable visual attention. Street lighting has also captured participants' visual attention as shown in Figures 6.4 (a) through (c) which aligns with the survey results in Figure 6.3.

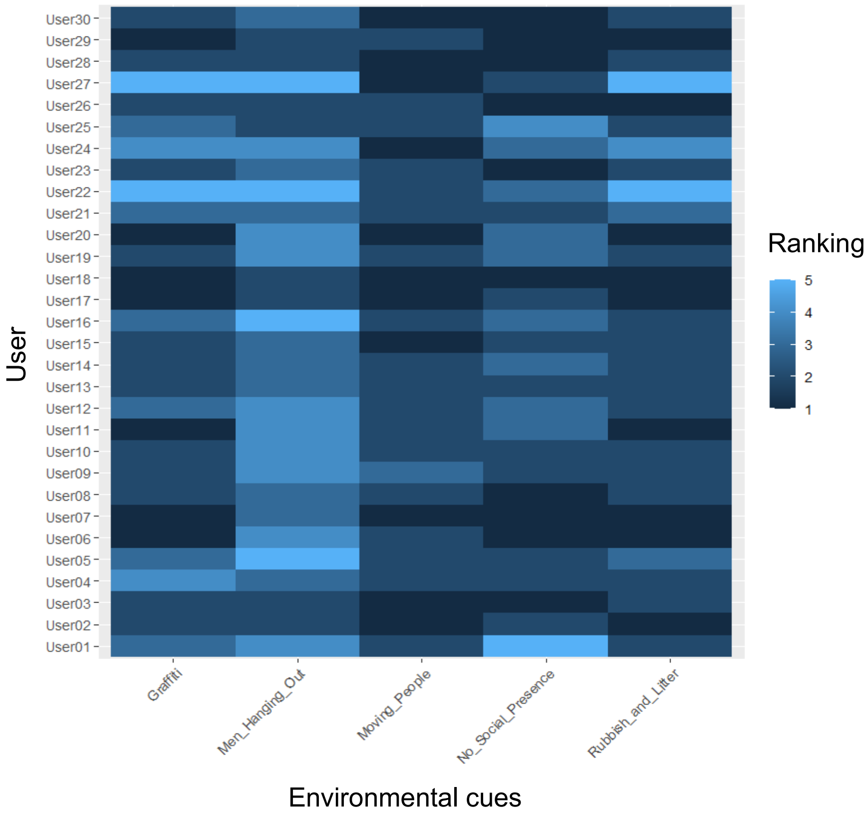
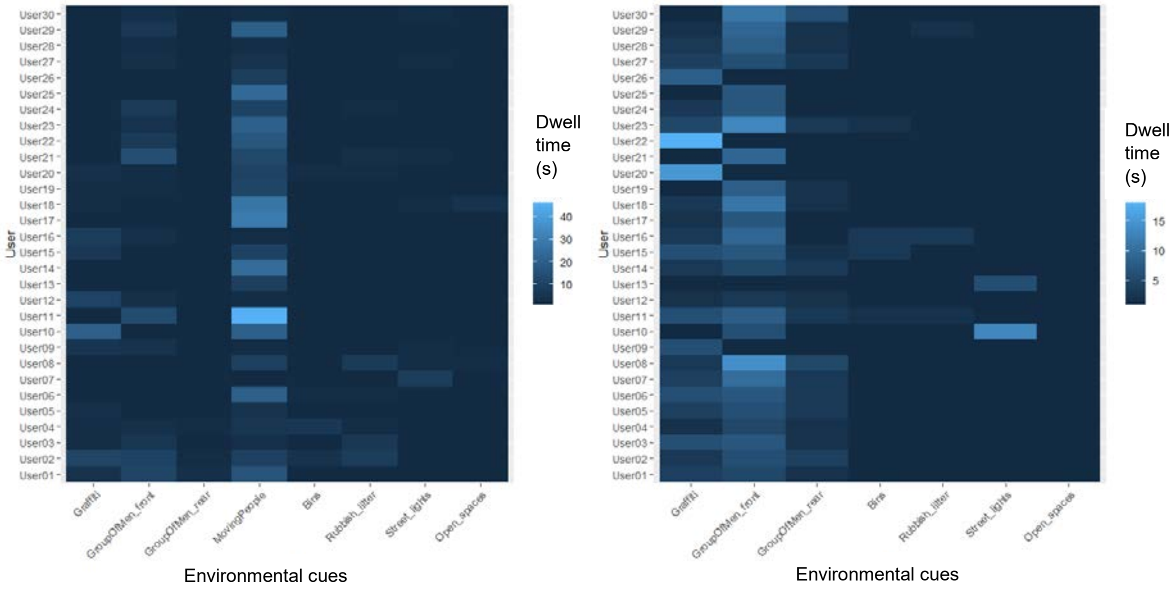


Figure 6.1: Participants' ranking against environmental cues for daytime – results from the follow-up survey questionnaire



(a) (b)

Figure 6.2: Gaze dwell time (daytime) against environmental cues in Scenario 01 (a) and Scenario 04 (b)

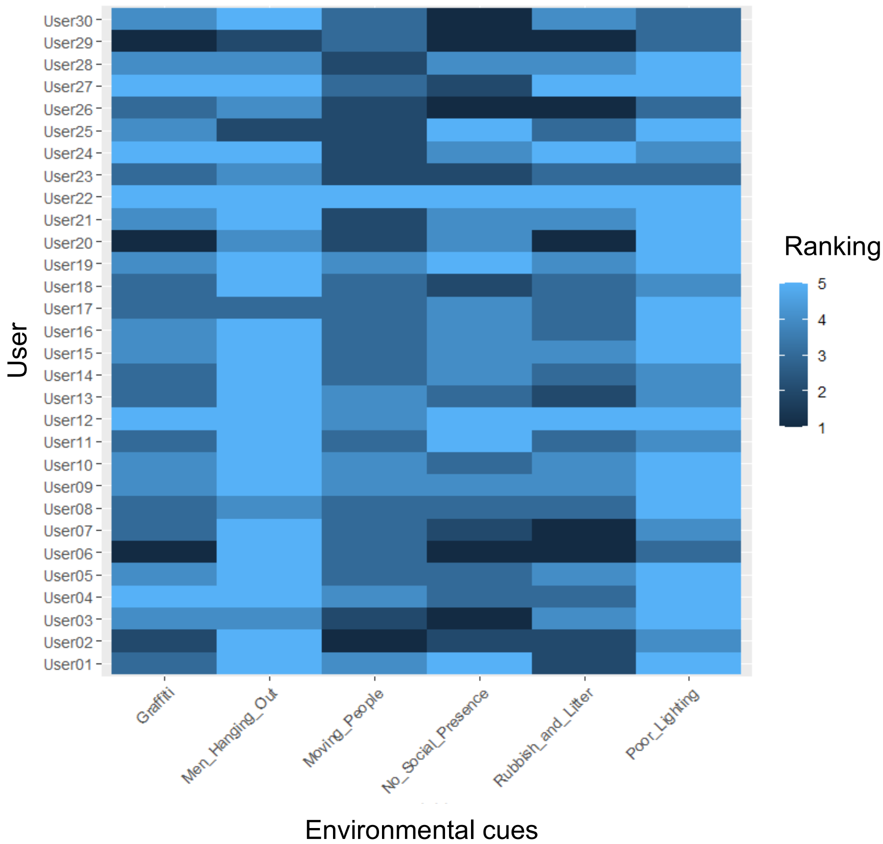
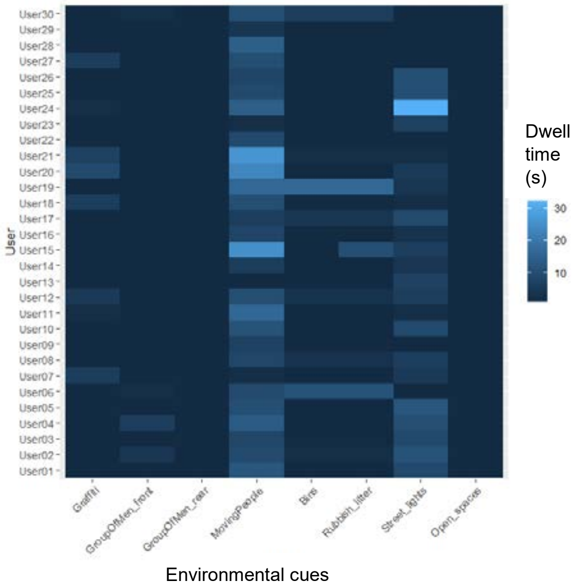
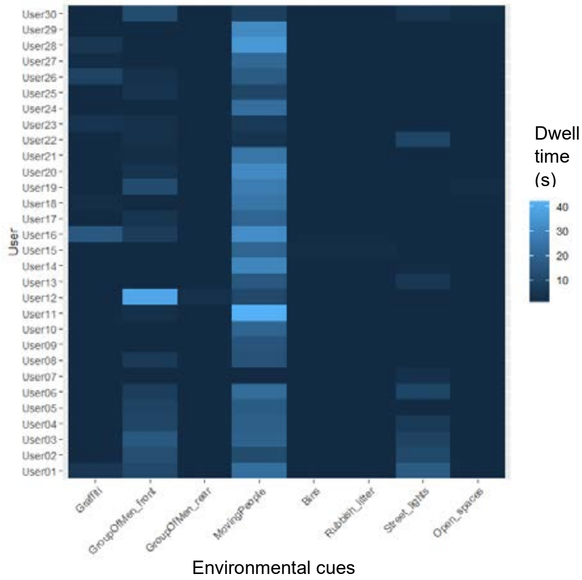


Figure 6.3: Participants' ranking against environmental cues for night-time – results from the follow-up survey



(a)



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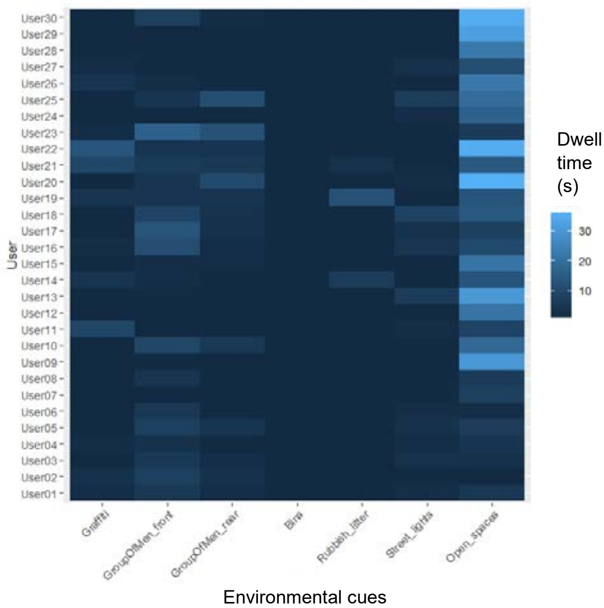


(c)

Figure 6.4: Gaze dwell time (night-time) against environmental cues in Scenario 02 (a), Scenario 03 (b), and Scenario 05 (c)

At the same time, the follow-up survey questionnaire asks participants to rank the environmental cues, it also limits the participants' perception to a more generalised scenario by asking 'walking through an alleyway, how would the presence of following environmental cues increase your perception of criminal risk?' Although the ranking obtained from posing such a question helps understand the impact of each environmental cue on their perception of criminal risk individually as if only one cue is present at a given time and space, as empirical findings in Figure 6.2(a) through 6.2(b) and Figure 6.4(a) through 6.4(c) suggest, this is far from how a person would perceive an alleyway or an environment in real-world as and when they navigate such spaces. Empirical findings from this study further suggest, as depicted in Figure 6.2(b) and Figure 6.4(c), that whenever moving people were not present, participants' visual attention shifted to another environmental cue both in the daytime and at night. When moving people are present in the alleyway, they are the most significant cue in terms of gaze dwell time at both the daytime and night, which speaks to the impact of dynamism when exploring the momentary and context-specific perceptions of criminal risk. When assessing the weightings of the likelihood of criminal risk (ranking from 1 to 5) against their gaze dwell time through the follow-up questionnaire survey (refer to Appendix C, Question 14), participants were asked to explain why there were mismatches, if any, between their weightings of the likelihood of criminal risk and their gaze behaviour i.e., gaze dwell time and gaze direction. According to survey results, 6 out of 30 participants considered moving people to not be a criminal risk at the daytime and another 11 participants ranked moving people as 2, thus stating that there is a low criminal risk at the daytime. However, their gaze behaviour i.e., gaze dwell time shows significant visual attention to moving people in Scenario 01 (Figure 6.2(a)). Survey results from these 6 participants found that their walkthrough experience was closely related to that of a real-world alleyway with pedestrians at the daytime and that they were immersed in this environment as they were doing the virtual walkthrough. Therefore, it was evident from their responses that they would pay more visual attention to dynamic cues when presented with such cues in the real world. On the contrary, a survey tool alone would break this immersion, resulting in somewhat biased responses.

On the other hand, only 1 participant had perceived moving people to not be a criminal risk at all at night. Similar to the daytime scenarios, their gaze behaviour (Figures 5.4 and 5.6 in Chapter 5, Section 5.2.1) at night suggests that there is somewhat significant visual attention to moving people in both Scenarios 02 and 03. According to survey results, this is influenced by how they would navigate a real-world urban alleyway with pedestrians at night-time i.e., they would look at people walking towards them from far away and divert their gaze direction as they get closer. Their response to assessing the mismatch between ranking and gaze dwell time suggests that dynamism poses a perception of greater criminal risk in an urban alleyway, particularly at night. Therefore, the assessment of gaze dwell time against participants' ranking, supported by participants' responses for mismatches between these suggests that virtual reality scenarios which present static images are not as realistic as virtual reality scenarios which present dynamic walkthroughs. This also points to dynamism posing a perception of greater criminal risk as opposed to still environmental cues such as graffiti, rubbish and litter lying around, particularly at night time.

Whilst empirical findings for daytime scenarios are consistent with participants' rankings against most environmental cues (i.e., survey findings), Figure 6.2(a) and Figure 6.2(b) depict varying lengths of gaze dwell time between the group of men at the beginning of the alleyway and the group of men at the end of the alleyway. The group of men at the start of the alleyway in Scenario 04 gained more visual attention than the group of men in Scenario 01, with a median value of 2.5 seconds in Scenario 01 and a median value of 7 seconds in Scenario 04. Whilst environmental context is the same in both Scenarios 01 and 04, the difference in context between the two scenarios is that Scenario 04 does not present moving people as a cue, thus, the absence of the dynamic variable, pointing towards the significant impact of dynamic behaviour on the perception of criminal risk.

Participants' rankings for daytime perceptions of criminal risk as mapped in Figure 6.1 (cross-referenced in Figure 5.11 in Chapter 5, Section 5.2.3) suggest that the group of men hanging out may increase people's perception of criminal risk. Empirical findings in Figures 6.2(a), 6.2(b), 6.4(a), 6.4(b), and 6.4(c) support this argument as the men hanging out at the start of the alleyway proved to have captured significant visual attention in both daytime and night-time scenarios except for Scenario 02 which presents a tunnelled-like alleyway at night. Thus, certain people in an environment can increase a person's perception of criminal risk. People generally fear other people and especially "scary" people, for which reason locations at which such encounters may occur are more likely to function as fear generators (Brantingham and Brantingham, 1995:9). Nevertheless, according to empirical findings (Figures 6.2(a), 6.2(b), 6.4(a), 6.4(b), and 6.4(c)), where exactly these groups of men are hanging out, for example their positioning along an urban alleyway, also plays an important role in understanding the variations in the perception of criminal risk. According to participants' explanations from the follow-up survey, the group of men hanging out at the end of the alleyway attracted less visual attention as they had reached the end of the alleyway, thus, resulting in a higher threshold for perceived criminal risk. This aligns with how levels of prospect, refuge, and escape are associated with perceptions of either greater criminal risk or lower criminal risk (Fisher and Nasar, 1992; Petherick, 2000; Cozens and Sun, 2019; Strandbygaard et al., 2022).

Graffiti, which is reflective of a lack of social order seems to have captured relatively significant visual attention in the daytime as shown in Figures 6.2(a) (Scenario 01) and 6.2(b) (Scenario 04). There are also varying lengths of gaze dwell time on graffiti between daytime scenarios 01 and 04. Graffiti in scenario 04 has gained more visual attention in the absence of moving people, which again emphasises on the significance of dynamism or dynamic behaviour in an environment in increasing the perception of criminal risk at the daytime. On the contrary, graffiti in urban alleyways is less often looked at during night-time (Figures 6.4(a), 6.4(b), and 6.4(c)), even though most participants (37%) perceive graffiti as high criminal risk, and 17% of them ranked presence of graffiti in the alleyway at night as very high criminal risk. Another 33% of participants consider graffiti to moderately increase their perception of criminal risk according to survey results. Participants whose gaze behaviour did not align with their rankings, explain this difference as influenced by the change of their behaviour and purpose at night, which is to get to the other side of the alleyway as quickly as possible while being observant of the immediate environment. Their explanations also revealed that the presence of moving people and men hanging out around the corners of the alleyway were more important to keep an eye on than the cues that were static. Thus, there is a tendency that people's perceptions of criminal risk might be attached to the view that there are people present in the environment who may be dangerous, rather than the observed occurrence of disorderly behaviour portrayed by graffiti and other signs of physical disorder such as broken windows, rubbish and litter lying around, and signs of vandalism (Hinkle, 2015), especially at the night-time. Concretely, urban environments with signs of physical disorder such as graffiti, litter on the streets, decayed buildings, and broken windows increase the perception of a loss of civil society, thus elevating the perception of criminal risk (Doran and Burgess, 2012). However, survey results compared to the observational eye gaze data suggest that the significance of signs of physical disorder such as graffiti is largely dependent on the time of day and spatial context of the environment, especially in the presence of other environmental cues.

Poor street lighting, as shown in Figure 6.3 (also see Figure 5.11 in Chapter 5, Section 5.2.3) can be associated with an increased perception of criminal risk. Whilst most participants (60%) consider an urban alleyway with poor lighting to have a very high impact on their perception of criminal risk (see Figure 5.11 in Chapter 5, Section 5.2.3), empirical findings in Figures 6.4(a), 6.4(b) and 6.4(c) indicate that this may vary depending on the design and context of the alleyway, level of lighting, and the presence of other environmental cues in the alleyway that people may perceive as a criminal risk. For example, street lighting in Scenario 02 which presented a curved, tunnelled, and well-lit alleyway at night has gained significant visual attention from 56% of participants (17 participants), ranging between 5-12 seconds with the lengthiest duration recorded at 32 seconds by an individual participant (Figure 6.4(a)). Whilst street lighting in both Scenarios 03 and 05 has captured less visual attention as opposed to that of Scenario 02, there is slightly more interest in lighting in Scenario 05 over that of Scenario 03 (Figures 6.4(a), 6.4(b) and 6.4(c)). Empirical findings in relation to street lighting also suggest as shown in Figure 6.4(b), that in poorly lit alleyways where pedestrians (moving people) are present, this can be perceived as a social cue that might be associated with heightened perceptions of victimisation risk. Conversely, participants' gaze behaviour in Scenario 05 which is a well-lit alleyway with only groups of men hanging out around the two corners of the alleyway indicates that 87% of participants (Figure 6.4(c)) were looking at open areas/spaces at the start of the alleyway, along the alleyway, and on the other side of the alleyway. These include spaces that are both visually and physically permeable, for example, spaces that are visible and open with one or few escape routes, and spaces that may accommodate more crowds, thus providing surveillance. According to participants' explanations for the difference between gaze dwell time and ranking for street lighting, participants tend to be more observant of where the lights are when an alleyway is curved, tunnelled, and well-lit (e.g., Scenario 02) and has pedestrians present, to reassure that their immediate environment does not pose a criminal risk. On the other hand, when an alleyway is poorly lit and has pedestrians and groups of men hanging out around the two corners of the alleyway (e.g., Scenario 03), participants' visual attention shifts to social presence, particularly to moving people, to establish a clear path and to avoid being close to people who may seem dangerous. Thus, in such a situation, the most significant environmental cue is the dynamic behaviour of people or social presence. Moreover, when an alleyway is well-lit, and visually permeable, but has groups of men hanging out at the beginning and end corners of the alleyway (e.g., Scenario 05), participants tend to be more observant of open spaces that they can run to and escape if their perceived criminal risk further increases. Thus, in Scenario 07 they were observant not only of the immediate environment but also of what cues could be laying ahead.

Whilst poor lighting certainly is negatively associated with perceptions of criminal risk (Brantingham and Brantingham, 1995; Nasar and Jones, 1997; Boyce et al., 2000; Koskela and Pain, 2000; Doran and Lees, 2005; Haans and de Kort, 2012; Guedes and Cardoso, 2013; Fotios et al., 2015a; Castro-Toledo et al., 2017; van Rijswijk and Haans, 2018; Park and Garcia, 2020; Mushtaha et al., 2022; Wang et al., 2023), empirical findings of this study emphasise how these perceptions may vary, depending on the level of illuminance (Son et al., 2023), design, and context of the alleyway, including the presence of other risk-provoking environmental cues.

Whilst the whole array of literature relating to perceived criminal risk states that these social and physical incivilities are significant in calculating criminal risk, past studies have not been able to identify how the presence of these cues may impact people's perception of criminal risk i.e., how significant these cues are when calculating criminal risk. Empirical findings of this study suggest that moving people are the cue that most participants' eyes are drawn to and looked at for longer, irrespective of the time of day. In the absence of moving people, men hanging out at the start of the alleyway and graffiti have captured their visual attention respectively, at the daytime, and open spaces at night-time. When there are moving people present, participants' visual attention is shifted to streetlighting, men hanging out at the beginning of the alleyway, men hanging out at the end of the alleyway, graffiti, and rubbish and litter lying around respectively, in the order of time spent looking at these cues. When corroborated with survey findings, whilst survey findings complement the empirical findings, there are variations in the perceptions as discussed in section 5.2.3 that are common to the participants. However, this also demonstrates that not all participants are the same. The fact that these variations are common is important, but the fact that these people are different is also important to consider. Such variations in their perceptions suggest the need to capture the moment, which comprises of both spatial and temporal dimension. It also implies the importance of identifying the environmental cues that people pay particular attention to, over and above other cues, in different contexts and at different times, which has been difficult to determine in past studies.

6.2.2 Summary of key findings

The findings from the descriptive comparative analysis of virtual reality experiment results and the follow-up survey results suggest that gaze, specifically gaze duration i.e., gaze dwell time, is reflective of women's perception of criminal risk. For example, they tend to direct their gaze towards environmental cues that they perceive to be threatening or indicative of potential danger. Empirical findings from the virtual reality experiment indicate that moving people, men hanging out at the beginning and end of the alleyway, and graffiti are the most intently looked at cues at the daytime. However, it is important to note that this is dependent on the context and the mix of environmental cues present in the alleyway. For example, when dynamic cues such as moving people are present, this tends to draw more visual attention. On the contrary, in the absence of dynamic cues at the daytime, men hanging out in the corners of the alleyway seem to draw more visual attention of the participants. Further, in the absence of dynamic cues, they also look more intently at graffiti. Whilst the same cues, which are moving people, men hanging out in either corner of the alleyway, and graffiti also stand out from survey findings for daytime, participants perceive men hanging out in the alleyway to pose a greater criminal risk than the other two cues. Therefore, it is evident that there is a variation between data from the two methods on what they consider to be more concerning at the daytime. This suggests that whilst gaze-based VR simulations can help uncover what cues are the focus of people's movement around a place, surveys may capture which of these cues inform their calculations of risk in a place. Nevertheless, survey findings for the daytime complement the empirical findings for the daytime, while accounting for variations in the level of perceived criminal risk across participants and scenarios.

Furthermore, empirical findings indicate that the men hanging out at the beginning of the alleyway, moving people, and poor lighting pose greater criminal risk at night-time than other cues. Survey findings also indicate that the presence of men in the alleyway and poor lighting are more prominent perceptual indicators of criminal risk. Whilst findings from both methods suggest that participants' gaze is reflective of their perception of criminal risk at night-time, empirical findings also suggest that their perception of criminal risk varies across scenarios, depending on the context and the mix of environmental cues.

Finally, it is evident from the findings that environmental cues that capture prolonged attention (e.g., dwell time) from a participant play an important role in their assessment of the risk posed by crime in the alleyway, as opposed to cues that evoke lesser attention. The findings also indicate that the significance of these environmental cues vary contextually and momentarily. The gaze-based virtual reality simulation helps uncover these momentary and context-specific variations of the perception of criminal risk. However, owing to the novelty of employing a gaze-based VR simulation to explore the perceptions of criminal risk, it was important to test the feasibility of the virtual reality experiment. Therefore, the next section presents findings on the feasibility of the VR Study, focusing on the effectiveness of using VR as a data collection technique.

6.3 The effectiveness of virtual reality as a data collection technique

Findings presented in Section 6.2 suggest the relevance of gaze (e.g., gaze dwell time) to explain the perception of criminal risk, thereby advancing our understanding of the association between the environment and the perception of criminal risk. Whilst shortcomings of the questionnaire survey to understand the perceptions of criminal risk can be compensated for by the strengths of data from the VR study, the question that remains is ‘do people find it comfortable and realistic to use virtual reality?’ Therefore, this section explores the effectiveness of using virtual reality simulations to acquire people’s perceptions of criminal risk, against several factors: level of immersion and realism, user-friendly and usability, and physical and emotional comfort and convenience of participants.

6.3.1 Immersion and realism

Immersion and realism are considered as key features of virtual reality technologies (Ryan, 2001). Immersion in virtual reality refers to the extent to which a user feels completely absorbed in a simulated virtual environment. This often results in the user experiencing a sense of presence in that virtual environment (Radianti et al., 2020). Realism can be described through five interpretations: realistic looking, realistic construction of the virtual environment, physiological realism, psychological realism, and the presence. Physiological realism refers to the sensory experience a user would have in the virtual space is similar to that of the real world. Psychological realism is when the functions and implementation seem realistic to the user, for example, walking speed (Perroud et al., 2019). The objective of achieving immersion is to enable users to step into the virtual world mentally and emotionally, temporarily suspending their awareness of the physical environment around them.

To this end, as part of the follow-up survey, participants were asked to rank the level of realism and immersion of the virtual alleyways in response to the following two questions:

“How would you rate the level of realism?”

1 - Very Poor

2 - Poor

3 - Fair

4 - Good

5 - Excellent

“How would you rate the level of immersion and sense of presence in the environment?”

1 - Very Poor

2 - Poor

3 - Fair

4 - Good

5 - Excellent

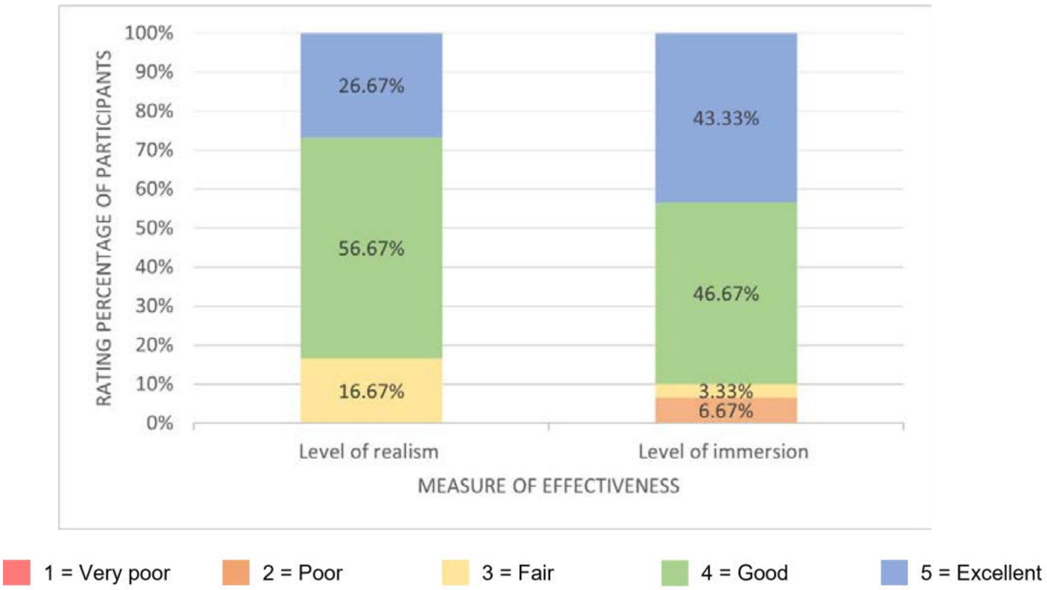


Figure 6.5: Participant ranking against the effectiveness of virtual reality: level of immersion and realism

Figure 6.5 illustrates the percentages of participants against each rank for the above presented questions. The findings indicate that most of the participants found both level of realism and immersion as ‘good’ (rank = 4). Whilst none of the participants have ranked the level of realism as ‘poor’, about 7% of them found the level of immersion to be ‘poor.’ There is also a considerable difference between the percentage of participants who have ranked two factors as ‘excellent’ (rank = 5), with about 43% ranking the level of immersion as ‘excellent’ (rank = 5), and only about 27% of them saying the same about the level of realism. In overview, Figure 6.5 shows that most of the participants, which is about 83%, found the level of realism of the virtual alleyways to be ‘good’ to ‘excellent.’ Further, about 90% of the participants considered the level of immersion as ‘good’ to ‘excellent.’

6.3.2 Usability

The concepts of user-friendly and usability play integral roles in shaping the design and effectiveness of virtual reality simulations and applications (Kamińska et al., 2022). Usability is referred to as the ease of use of a system. It encompasses the broader evaluation of the effectiveness, efficiency, and satisfaction of user interactions in virtual reality, including aspects such as ease of navigation, and user-friendly (Chandra et al., 2019). Therefore, this study considers three aspects of the virtual reality simulation based on its functions, which speak to the level of usability of it.

As shown in Figure 6.6, these aspects are easy and smooth navigation, speed of navigation, and user-friendliness, mainly in terms of clear instructions for navigating using the virtual reality controllers (as explained in Chapter 3). The findings, as illustrated in Figure 6.6, reveal that most of the participants (about 43%) found navigating the simulated alleyways easy and smooth, thus ranked ‘excellent’ (rank = 5). Most of them (50%) also found the virtual reality simulation user-friendly who ranked this as ‘excellent’ (rank = 5). However, only about 23% of the participants considered the speed of navigation as ‘excellent’, whilst most of them (about 57%) thought it was ‘good’ (rank = 4). On the other hand, about 3% of the participants found speed of navigation to be ‘very poor’ (rank = 1) and about 7% of them thought it was ‘poor’ (rank = 2). Moreover, about 17%, 10%, and about 7% of the participants stated that ease of navigation, speed of navigation, and user-friendly were ‘fair’ (rank = 3) respectively. All in all, most of the participants found all three aspects related to usability of the virtual reality simulation ‘good’ to ‘excellent.’

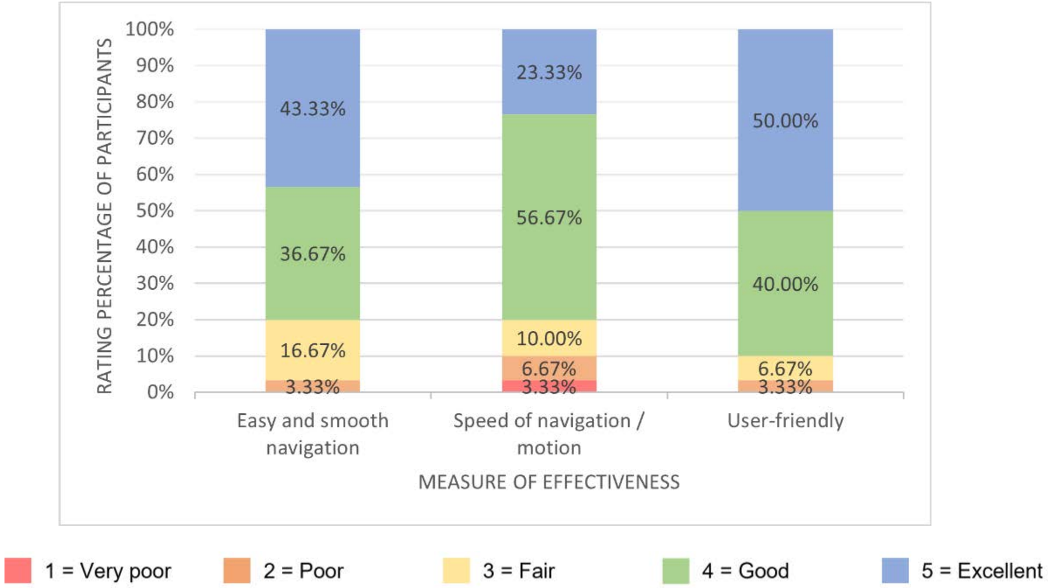


Figure 6.6: Participant ranking against the effectiveness of virtual reality: level of usability

6.3.3 User comfort

Extending beyond the measures of effectiveness of the virtual environment, the design and configuration of virtual reality equipment, and the surrounding physical space have significant implications for user comfort, safety, and overall well-being (de França and Soares, 2018). This careful consideration of factors such as user posture and the arrangement of the physical space to optimise user comfort, minimise physical strain, and mitigate potential health risks is referred to as ergonomics in the context of virtual reality (de França and Soares, 2018; Souchet et al., 2023). Virtual reality sickness, also commonly referred to as cybersickness or virtual reality-induced motion sickness is another key aspect when ensuring user comfort in these experiments. Virtual reality sickness involves a range of symptoms such as nausea, dizziness, and disorientation, which are triggered by a mismatch between what the user sees in the virtual reality environment and the sensory information their body receives, leading to a feeling of sensory conflict (Chattha et al., 2020).

To this end, this study also explores the level of comfort that participants experienced in relation to their physical and emotional comfort, feelings of dizziness, and the environment of the virtual reality lab space i.e., the arrangement of the physical space. In response to this, participants were asked to rank the level of comfort, including both physical and emotional, if they ever felt dizzy during the experiment, and how they felt about the physical space of the virtual reality lab through the following questions:

“How comfortable were you during the experiment?”

1 - Never

2 - Rarely

3 - Sometimes

4 - Often

5 - Always

“Did you feel dizzy at any point during the experiment?”

1 - Never

2 - Rarely

3 - Sometimes

4 - Often

5 - Always

“How would you rate the lab space for this particular experiment?”

1 - Too small

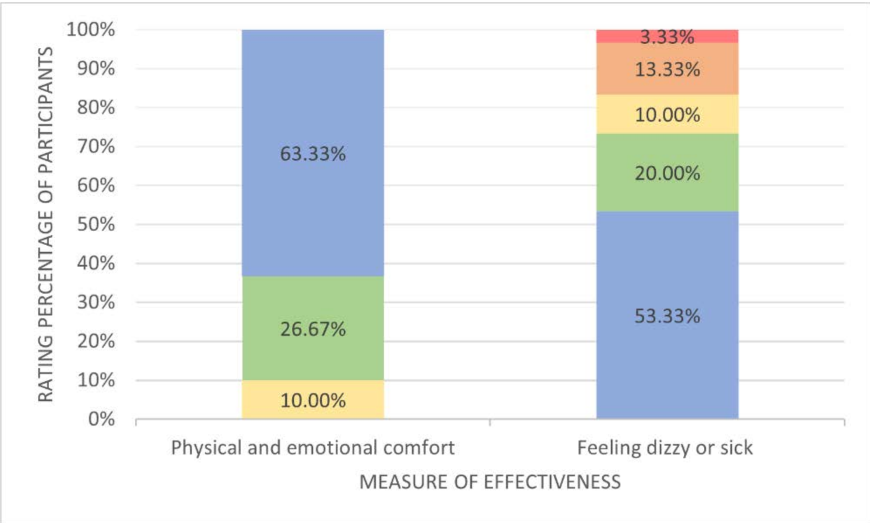
2 - Small

3 - Perfect

4 - Big

5 - Too big

As illustrated in Figure 6.7, it is evident from the findings that most of the participants (about 63%) were “always” (rank = 5) comfortable during the virtual reality experiment. Whilst none of them stated as being “rarely” (rank = 2) or “never” (rank = 1) comfortable during the experiment, 10% of the participants stated that they were only “sometimes” (rank = 3) comfortable. With about 27% of the participants stating that they were “often” (rank = 4) comfortable, it is possible to say that most of them, which is 90%, were “often” to “always” comfortable during the experiment.



Level of comfort scale:

1 = Never   2 = Rarely   3 = Sometimes   4 = Often   5 = Always

Level of virtual reality sickness (dizziness) scale (reversed):

1 = Never   2 = Rarely   3 = Sometimes   4 = Often   5 = Always

Figure 6.7: Participant ranking against the effectiveness of virtual reality: level of user comfort

Figure 6.7 also indicates that most of the participants (about 53%) “never” (rank = 1) felt dizzy during the experiment, whilst about 3% of them “always” felt dizzy and sick. Another 13% of the participants “often” (rank = 4) experienced these symptoms, and 10% of them only “sometimes.” (rank = 3) experienced them. However, with another 20% of the participants “rarely” (rank = 2) experiencing any dizziness or other virtual reality induced symptoms such as nausea (i.e., feeling sick), most of them, which is 73%, “rarely” or “never” experienced these symptoms. Further, it is important to note that participants were allowed to take breaks or withdraw at any point during the experiment when needed. This measure was taken to ensure maximum comfort and to minimise and avoid participants from experiencing virtual reality induced sickness.

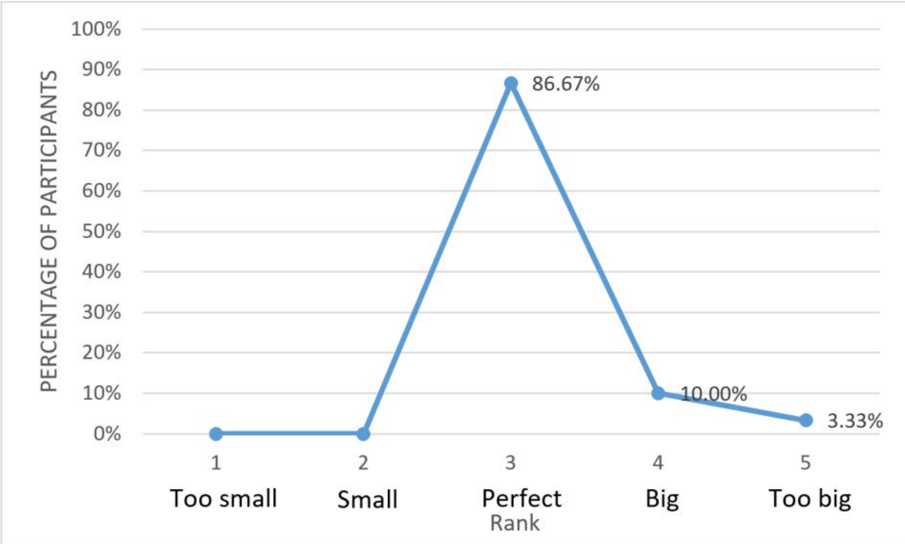


Figure 6.8: Participant ranking against the effectiveness of virtual reality: laboratory space for the virtual reality experiment

The arrangement of physical space for a VR experiment is crucial for ensuring a safe, comfortable, and immersive experience for participants. To create an optimal environment, several factors were considered. First, it was ensured that the virtual reality lab space is free of obstacles and hazards to prevent any accidents or injuries during the virtual reality experiment. Second, the space in the lab was rearranged to ensure participants had adequate space to accommodate the full range of movements required by the virtual reality simulation, for example, turning, rotating, and gesturing. Moreover, it was also ensured that the participants had adequate space for any physical reaction that may be triggered in response to their perception of criminal risk while navigating the simulated alleyways. The findings as shown in Figure 6.8 indicate that most of the participants, which is about 87%, found the arrangement of the physical space "perfect" (rank = 3) and stated that they had adequate space for movement during the virtual reality experiment. On the contrary, 10% of the participants stated that the space was “big” (rank = 4) for the experiment, and another 3% suggested that it was “too big” (rank = 5).

6.3.4 Summary of key findings

Owing to the novel design and development of a gaze-based VR simulation to acquire data on women’s perception of criminal risk, it was deemed necessary to test its effectiveness as a data collection technique, focusing on the experience of participants during the experiment. This involved assessing the design and layout of the virtual environment and the physical lab space to ensure user comfort, safety, and overall well-being during the experiment. To this end, participants were asked eight questions related to their virtual experience and how they felt during the experiment, highlighting their comfort.

Findings in Section 6.3 suggest that the level of immersion and realism of the virtual reality simulation was appropriate and adequate for this study as most of the participants found both level of realism and immersion as ‘good.’ However, level of immersion, when considered individually level of immersion was better than the level of realism as the latter of considered “excellent” by only 27% of the participants, whilst the former was ranked “excellent by 43% of them. Most of the participants also ranked easy and smooth navigation, and the virtual reality simulation being user-friendly as “excellent.” On the other hand, speed of navigation was considered “good” by most of them. Moreover, 90% of the participants were “often” to “always” comfortable during the experiment, with the majority out of this, which is about 63% being “always” comfortable. Furthermore, 17% of the participants experienced virtual reality induced symptoms such as dizziness and nausea “often” to “always”, with only about 3% experiencing these “always.” In contrast, about 53% of the participants “never” experienced virtual reality induced symptoms. With reference to the arrangement of physical space in the virtual reality lab, most of the participants (87%) felt this was “perfect”, whilst about 13% of them thought it was “big” to “too big.”

6.4 Discussion

This chapter set out to explore the association between gaze behaviour and the perception of criminal risk through triangulating data generated from the virtual reality experiment and the follow-up questionnaire survey. Understanding the association between gaze behaviour and the perception of criminal risk has implications for the development of effective crime prevention strategies and the design of safer urban spaces. By gaining insights into how individuals visually process their surroundings and assess criminal risks, it is possible to inform the development of interventions that enhance situational awareness.

Section 6.2 of this chapter presents a comparison of the empirical findings and survey findings, which demonstrate that gaze duration i.e., gaze dwell time, is reflective of women's perception of criminal risk. However, it was also found through triangulating data from these two methods that there is a variation between data from the two methods on what cues participants perceive as a potential criminal risk when navigating urban alleyways. This is mainly true for the findings related to the daytime. Further, this may speak to the limitation of using a survey tool alone for capturing people's perception of criminal. For example, whilst gaze-based VR simulation helps capture real-time and more accurate perceptions based on gaze behaviour, survey tools may capture perceptions based on what cues people think are associated with heightened perceptions of criminal risk.

Such mismatches between data from the two methods further emphasise the momentary and context-specific nature of the perceptions of criminal risk, which are difficult to capture using survey tools (Solymosi et al., 2021; Chataway and Mellberg, 2021). For example, when dynamic cues such as moving people are present, this tends to draw more visual attention. On the contrary, in the absence of dynamic cues at the daytime, men hanging out in the corners of the alleyway seem to draw more visual attention from the participants. The reasons for such misalignments of data between the two methods are explained in Chapter 5.

Findings from both methods also suggest that participants' gaze is reflective of their perception of criminal risk at night-time. This indicates that what participants look at more intently is reflective of that which they consider to be more significant to them when calculating potential criminal risk. However, the empirical findings from the gaze-based VR simulation suggest that participants' perception of criminal risk is dependent on the context, moment, and mix of environmental cues to a greater extent. This highlights that gaze behaviour (for example, dwell time and direction), which refers to the focus of an individual's visual attention, plays a crucial role in how individuals perceive and evaluate potential threats as and when they navigate urban spaces. Further, this could reveal the prioritisation of visual cues when calculating criminal risk in urban spaces, which speaks to the relative significance of these environmental cues. Moreover, the findings of this study are potentially transferrable to other walkthrough methods that examine physical activity spaces. Whilst most of the current methods cannot be used to determine how personal assessments of victimisation risk vary while an individual is navigating their activity space, it is evident from the findings of Section 6.2 that gaze is a useful measure of the perception of criminal risk, which advances existing literature on the measurement of the perception of criminal risk.

Although, findings in Section 6.2 suggest that gaze is a potentially useful measure of the perception of criminal risk, it is equally important to understand participants' experience when using VR technology and what they think of this gaze-based VR simulation. For example, how realistic and immersive is the virtual environment, how user-friendly is it, how comfortable are they in using VR, and whether they experience virtual reality-induced symptoms such as dizziness and nausea. Therefore, Section 6.3 presents survey findings on the effectiveness of VR as a data collection technique, focusing on the degree of immersion and realism, usability, and user comfort, including virtual reality sickness.

The level of immersion and realism in VR has significantly advanced in recent years, transforming the way users engage with virtual environments and experiences. However, there seems to be lack of realism and immersion in virtual environments used in design research (Kalantari and Neo, 2020). One reason for this is the use of static representations to present a real-world phenomenon. Secondly, there are also concerns around navigating in virtual environments (Kalantari and Neo, 2020).

Findings of this study suggest that most of the participants were satisfied with the degree of realism and immersion of the gaze-based VR simulation. On the other hand, about 7% of the participants felt that the level of immersion was ‘poor.’ As explained by participants, incorporating sound would help improve the level of immersion.

Navigation is one of the most interactive tasks in a virtual reality environment (Bowman et al., 2001). According to the findings of this study, most of the participants have felt that navigation, including its speed was smooth and easy, which added to their overall experience. In contrast, poorly designed navigation interfaces can have adverse effects on user experience, resulting in mental stress, low usability, and virtual reality sickness (Bozgeyikli et al., 2019). This shows that whilst these factors were ranked individually, they seem to relate to one another to some extent. For example, poor navigation could negatively impact user experience and cause virtual reality sickness. Moreover, poor navigation could also make the virtual environment less realistic and immersive.

Although VR has rapidly evolved, offering immersive and interactive experiences across various domains, the widespread adoption of virtual reality has raised concerns about its ergonomic implications, particularly in relation to user comfort, safety, and overall well-being (de França and Soares, 2018). The ergonomics of VR encompass the design and optimisation of VR simulations to ensure users' physical and cognitive health while engaging in VR experiences. In response to this, the physical and emotional comfort of the participants were also assessed. Most (90%) of the participants were “often” to “always” comfortable during the experiment and about 53% of the participants “never” experienced virtual reality-induced symptoms. Moreover, the arrangement of the physical space of the lab also played an important role in improving the participants’ overall experience, and most of them felt the space was adequate and appropriate for the experiment. In contrast, it was found that some participants experienced slight discomfort because of wearing the virtual reality head-mounted display over their pair of glasses.

Overall, this chapter looks at the association between people’s gaze and the perception of criminal risk, by triangulating data from two methods: a gazed-based VR simulation, and a survey tool. This study further extends the survey tool to capture participants' experiences in relation to the VR experiment. In doing so, this study not only identifies the potential of using gaze as a measure of the perception of criminal risk, but also suggests a safe and effective way of probing the association between environment and the perception of criminal risk. Thus, it is safe to conclude that gaze is a useful measure of the perception of criminal risk and gaze-based VR simulation is an efficacious data collection tool.

Chapter 7

Conclusion

7.1 Introduction

The overarching aim of this thesis has been to advance our understanding into the momentary perceptions of criminal risk and to discern the interplay of contextual factors, for example, visual environmental cues, on this perception. Traditionally, data and studies on the perception of criminal risk have largely relied on self-reports and other survey methods. Existing literature has emphasised the limitations of these traditional methods in capturing how individuals perceive criminal risk in real life and what drives their perceptions as and when they navigate urban spaces. Existing studies have also highlighted the importance of understanding the perception of criminal risk as a dynamic multi-faceted phenomenon (Solymosi et al., 2015; Chataway and Hart, 2019).

To this end, this study sought to explore the intricate relationship between the environmental design, incivilities, and the perception of criminal risk, employing a novel approach by utilising gaze-based VR simulation to comprehend the dynamics of context-specific and momentary perceptions of criminal risk. Findings open prospects for the association between the environment and the perception of criminal risk to be understood through theoretical and methodological triangulations, which help uncover its context-specific and momentary nature. This chapter primarily serves to remind readers of the narrative that has been traced and is structured in the following fashion: Section 7.2 summarises the key findings reports in each chapter. Section 7.3 then reports the key contributions of the thesis. Section 7.4 explains the limitations of the study, and finally, Section 7.5 brings the chapter to a close by setting out a future research agenda.

7.2 Chapter re-cap

Following an introductory first chapter, Chapter 2 explained the theoretical underpinnings of the study, providing a comprehensive review of the existing literature on the perception of criminal risk, its correlates, and its measurement. In doing so, it demonstrated the need to examine the perception of criminal risk in context and the moment, which is difficult through traditional survey techniques, thereby opening a discussion into what is lost by surveys. To this end, the chapter concluded by highlighting the motivation to consider new approaches that help examine the context-specific and momentary perceptions of criminal risk.

In response to Chapter 2, Chapter 3 presented a critique of emerging methodologies used to assess the perception of criminal risk, a review of the development and relevance of a gaze-based VR simulation, and the method of the thesis, including the framework for the VR experiment. In doing so, it described the selection of participants, the methods for data collection, the practical challenges that the thesis faced, and the ethical considerations of the study. With a suitable and relevant method identified, the experimental framework proposed in this chapter fulfils the second objective of the thesis: to develop a novel approach to obtain momentary and context-specific perceptions of criminal risk.

Chapter 4 provided a detailed account of the design of the gaze-based VR simulation that was presented in Chapter 3. In approaching this challenge, the argument has been made for treating the perception of criminal risk, environmental design, and incivilities as related but theoretically distinguishable phenomena. To this end, this chapter designed a gaze-dependent VR methodology augmented by a follow-up questionnaire survey to remedy the theoretical and methodological shortcomings identified in Chapters 2 and 3, highlighting its novelty through data, theoretical, and methodological triangulation.

Chapter 5 reported the findings generated from the VR experiment and the follow-up survey. The chapter began with presenting the empirical findings (from the VR experiment) and survey findings, each sub-section focusing on the association between environmental design, incivilities, and the perception of criminal risk. Then, it described the momentary and context-specific nature of the perception of criminal risk, emphasising the relative significance of these environmental cues as participants navigated urban alleyways. It also explicated the importance of considering demographic characteristics such as age, gender, ethnic origin, religion, socio-economic status, and people's previous experience in relation to crime and criminal risk when investigating the relative significance of environmental cues in people calculating criminal risk for a more holistic view of the perception of criminal risk.

Chapter 6 presented a detailed comparison between the empirical findings and survey findings for triangulation. In doing so, this chapter examined the potential synergies between the use of gaze as a measure of the perception of criminal risk. it was evident from the findings that, which cues participants look at more intently are reflective of that which they consider to be more significant in calculating criminal risk. This chapter also indicated that the significance of these environmental cues varies contextually and momentarily, and the gaze-based VR simulation was useful in uncovering these context-specific and momentary variations of the perception of criminal risk. Then, it assessed the effectiveness of VR as a data collection technique, emphasising the level of immersion and realism, usability, and user comfort, thereby further extending the survey tool to capture participants' experiences in relation to the VR experiment. Therefore, this chapter not only identified the potential of using gaze as a measure of the perception of criminal risk, but also suggested a safe and effective way of probing the association between environment and the perception of criminal risk using VR methods.

7.3 Key contributions

Given the content of the chapters detailed above, the key contributions of this thesis are three-fold: conceptual, methodological, and empirical. These contributions directly address the aim and objectives of this thesis:

Aim:

To advance our understanding into the momentary perceptions of criminal risk and to discern the interplay of contextual factors, for example, visual environmental cues, on this perception.

Objectives:

1. To establish a conceptual framework capable of informing the design and assessment of an investigation of the momentary and context-specific perceptions of criminal risk in alleyways.
2. To develop a novel approach to obtain momentary and context-specific perceptions of criminal risk.
3. To critically evaluate the efficacy of virtual reality as a tool to explore women's perceptions of criminal risk.

Firstly, this thesis makes a significant contribution to the field of urban studies and criminology by amalgamating urban design theory and criminological theory, thereby introducing a more nuanced conceptual model for understanding people's perceptions of criminal risk. By integrating key concepts from both disciplines, this thesis offers a comprehensive framework that elucidates the intricate interplay between the environment and the perception of criminal risk. This synthesis not only enriches the existing literature, but also provides a more holistic perspective that acknowledges the multi-faceted influences shaping people's perceptions of criminal risk as and when they navigate urban spaces.

Secondly, this thesis makes a key methodological contribution through testing the relevance of new technologies to explore momentary and context-specific perceptions of criminal risk. By approaching the same concept of the perception of criminal risk and the two research questions with two different tools i.e., a gazed-based VR simulation and a follow-up survey tool, this thesis triangulates data and methods, thereby reducing bias that comes from using a single method or data source and enhancing the validity of findings. Further, by incorporating innovative technological tools and methods such as eye-in-head gaze shifts, VR, and game engines (e.g., Unreal Engine 4), this thesis pushes the boundaries of conventional data collection techniques, enabling a more dynamic and nuanced assessment of individuals' perceptions of criminal risk in real-time contexts.

Thirdly, findings from this thesis have contributed to our understanding of context-specific and momentary perceptions of criminal risk when people navigate alleyways. Through meticulous scrutiny of the research method's outcomes, the study not only validates the reliability and validity of the data but also highlights the significance of these findings in elucidating the intricate nuances of how individuals perceive and respond to perceived criminal risks in their environment. Empirical findings suggest that the level of significance of visual environmental cues varies when these cues are presented together and not individually. Thus, gaze-based VR simulation helps uncover what environmental cues people pay more visual attention to over and above other cues across space and time, thereby examining their relative significance. This is key to advancing our understanding of the association between the environment, incivilities, and the perception of criminal risk. Therefore, this thesis not only identifies the extent to which these findings corroborate existing literature in relation to the impact of environment and incivilities on the perception of criminal risk but also advances our understanding of the association between the environment and the perception of criminal risk.

Further, the VR experiment explored the gaze behaviour of people, and through methodological triangulation, it was evident that gaze is relevant to exploring the perception of criminal risk. Therefore, this thesis also opens a novel discussion around the question 'Is it that which we spend the most time looking at, that has a clearer association with the perceptions of criminal risk?' Thus, this study not only identifies the potential of using gaze as a measure of the perception of criminal risk but also suggests a safe and effective way of probing the association between the environment and the perception of criminal risk using VR methods. In addition to advancing our understanding of the association between the environment and the perception of criminal risk by examining the relative significance of environmental cues, this thesis also suggests that gaze is a useful measure of the perception of criminal risk and that gaze-based VR simulation is an efficacious data collection tool, thereby further adding to the empirical contribution.

Finally, this thesis converges several domains of knowledge, including urban design, criminology, technology and science studies to address the core questions in social science, which have been left wanting to address for some time. Therefore, the contributions of this thesis are relevant to a whole range of urban analytical questions, which are not just about perceptions of criminal risk, but could be about value judgements, social emotions, perceptions of safety, people's preferences, or perceptions of space.

7.4 Limitations

This thesis, whilst advancing our understanding of the relationship between environment and perceptions of criminal risk, is not without its limitations. Firstly, the use of a small sample poses certain limitations. With a limited number of participants, the generalisability of the findings to the broader population is constrained (Vasileiou et al., 2018), potentially limiting the applicability of the research outcomes to diverse contexts and demographics. Although this thesis primarily focuses on data description rather than the development of statistical tools, an increased sample size may have allowed for more robust statistical analyses to identify significant associations between environmental cues. Secondly, using a single social group of women aged between 19 and 30 years as the primary sample in this study underscores the need for caution in the interpretation and generalisability of the findings. Whilst this limitation may restrict the applicability of the research outcomes to other social groups or communities, selecting a single social group discounts variance in response that might be generated by intersectionalities such as gender, age, race and ethnicity, sexual orientation, and physical ability.

Moreover, the level of realism of the VR simulation could be compromised to a certain extent as virtual urban environments may not fully replicate the complexities of real-world urban alleyways or other settings (Hamad and Jia, 2022; Van Gelder, 2023), it was not ideal to conduct the study in the real world (both daytime and night-time) due to certain ethical considerations such as health and safety risks. Therefore, conducting the experimental study in a controlled lab environment was necessary to ensure maximum safety and protection of the participants, researchers and the devices used. Another potential limitation is the delay between a user's movements and the visual feedback from a VR head-mounted display. This is caused when the tracking of the head-mounted display fails to keep pace with the user's movements, which not only diminishes their sense of immersion by decreasing the level of realism but can also lead to feelings of dizziness or virtual reality-induced symptoms and effects (Chattha et al., 2020; Hamad and Jia, 2022). Furthermore, the level of realism could be impacted owing to participants being seated during the VR experiment, thus causing their eye level to be less realistic. Whilst it is possible that some participants may have experienced physical discomfort or motion sickness during the VR experiment, every effort has been made to ensure that physical, social, psychological and all other types of discomforts or harms were kept to an absolute minimum. Virtual reality-induced symptoms and effects can be caused by several factors, including the hardware and software used, and properties related to the individual. For example, poorly designed virtual urban environments, low refresh rates from slow hardware, and a user's susceptibility to motion sickness may each negatively affect the VR experience.

As a practical solution, enhancing the realism of VR scenarios through high-quality graphics and detailed environmental design can increase the level of realism, which, in turn leads to improved ecological validity. Furthermore, participants can be screened for susceptibility to motion sickness and consider alternative methods for those who are highly sensitive. Whilst advancements in VR hardware have reduced the occurrence of these issues, they have not entirely resolved them (Van Gelder, 2023).

Another limitation of using VR to study the perceptions of criminal risk can be the potential for participants to behave differently in VR than they would in real life due to their awareness of the virtual or artificial environment (Van Gelder, 2023). For example, what participants do in virtual urban environments may not necessarily mirror their behaviours in real-life situations. Therefore, the generalisability of these findings will be contingent on several factors (Van Gelder, 2023). Whilst some studies have demonstrated correspondence between behaviour in the real world and in the virtual environment (Slater et al., 2006; Nee et al., 2019), further research is needed to examine the extent to which these findings remain consistent across different situations, conditions, and among different populations. Moving forward, improving our understanding of the extent to which VR findings around risk perceptions can be generalised to other contexts will be imperative (Van Gelder, 2023).

Furthermore, relying solely on visual cues in virtual reality to study the perceptions of criminal risk comes with limitations. For example, visual cues may not capture the full spectrum of sensory inputs present in real-life situations, potentially leading to incomplete or skewed perceptions of risk. Factors such as soundscape (auditory), smellscape (olfactory), and different environmental contexts (e.g., different weather conditions) are crucial in shaping one's perception of risk but may be lacking or misrepresented in visual-only virtual urban environments (Lyu et al., 2023). By integrating these multisensory inputs (e.g., soundscape and smellscape) and different environmental contexts (e.g., weather conditions) into VR simulations, researchers can create more immersive and realistic urban settings, mirroring real-world experiences more accurately (Toet and van Schaik, 2012). This enables a deeper understanding of how individuals perceive and respond to criminal risks in these urban settings, leading to more robust findings.

Finally, a limitation pertaining to the follow-up survey is the phrasing of the question "Walking through an alleyway, how would the presence of following environmental cues increase your perception of criminal risk?" This question presents a limitation due to its leading nature (Tourangeau et al., 2000; Krosnick, 2018). By using the term "increase," the question implies that all listed environmental cues would elevate the perceptions of criminal risk. However, this assumption may not hold true for every individual or scenario. Some environmental cues might indeed heighten perceptions of risk, while others could have neutral or even mitigating effects. The wording of the question may inadvertently bias responses toward expecting an overall escalation in perceived risk, potentially overlooking nuances in how different cues are perceived and interpreted. Therefore, a more neutral phrasing that allows for varied responses without presupposing an increase in perception would yield a more comprehensive understanding of individuals' perceptions of criminal risk in urban alleyway settings.

7.5 Future research agenda

The findings and insights from this thesis provide a robust foundation for future research that can further expand and enrich the understanding of momentary perceptions of criminal risk and the influence of visual environmental cues. Building on this groundwork, a promising avenue for future research lies in conducting longitudinal studies that examine how individuals' perceptions of criminal risk evolve over time in response to changing environmental stimuli. By tracking these perceptions longitudinally, researchers can uncover the dynamic nature of risk assessments and identify the factors that contribute to the persistence or alteration of these perceptions within diverse socio-cultural contexts. Furthermore, future research could delve into the intersectionality of various demographic factors, such as age, gender, race, ethnicity, sexual orientation, physical ability, and socio-economic status, and their impact on individuals' interpretations of visual cues related to criminal risk. Exploring how different demographic groups perceive and respond to these cues can provide valuable insights for tailoring targeted interventions and policy initiatives that address the specific needs and concerns of diverse communities.

Additionally, incorporating advanced technologies, such as eye-tracking and other physiological sensors (e.g., galvanic skin response (GSR), and heart rate) could offer innovative methods for creating immersive and dynamic environments to study how individuals perceive and navigate through different risk scenarios. This also enhances user experience and research precision (Meehan et al., 2002). Further, physiological data provide objective insights into user engagement and perceptions, which are invaluable for measuring the perceptions of criminal risk or other emotional responses. Moreover, future studies could upscale the VR experiment by increasing the sample size to include more diverse and representative populations, which would enhance the generalisability of the findings. This also enables a more robust statistical analysis.

Finally, soundscapes and smellscapes hold promise as innovative avenues in VR for examining the perceptions of criminal risk. By integrating immersive auditory (soundscape) and olfactory (smellscape) stimuli, researchers can create virtual environments that closely mimic real-world settings and elicit authentic perceptions (Toet and van Schaik, 2012; Lyu et al., 2023). For instance, the sound of footsteps in deserted alleyways or the smell of urban decay combined with visual cues may evoke more accurate perceptions of risk. Such VR simulations offer a controlled platform to explore how sensory cues contribute to the perceptions of criminal risk and inform strategies for planning and designing safe and inclusive urban settings.

By embracing these future research directions, scholars can continue to deepen our understanding of the complex interplay between environmental cues and the perceptions of criminal risk, thereby paving the way for more effective and evidence-based strategies for enhancing community safety and well-being.

In conclusion, this thesis has undertaken a pioneering exploration into the realm of criminal risk perception, leveraging the innovative combination of VR technology and gaze data analysis. By immersing participants in virtual urban alleyway simulations and tracking their gaze behaviour (e.g., dwell time) in real time, this study has gained unprecedented insights into the cognitive processes underlying risk assessments. The significance of this study extends beyond academia, with implications for urban planning and design, law enforcement, and community development. By deciphering the factors that shape individuals' perceptions of criminal risk, this thesis paves the way for targeted interventions and proactive strategies aimed at enhancing public safety, security, and well-being. The findings presented in this thesis underscore the transformative potential of interdisciplinary research and technological innovation in addressing pressing societal challenges.

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Appendices

Appendix A – Participant Recruitment Flyer

Manchester Metropolitan University

DO TECHNOLOGICAL ADVANCES AND INNOVATIONS FASCINATE YOU?

PARTICIPATE IN A RESEARCH STUDY ON THE USE OF VIRTUAL REALITY FOR FEAR OF CRIME DATA

You may qualify to participate if you:

- are a woman
- are between 19 and 30 years old

Potential benefits:

Experience virtual reality technology and know some of its uses in academic research AND get rewarded upon participation!

TO SECURE A SPOT:

Please scan the QR code below and register:

Participation involves:

- Approximately a 20-minute long virtual reality experience
- Followed by a 5 to 10-minute long questionnaire
- A cash reward of £25 upon participation

Date:

15 – 22nd of June, 2022 (+2 days flexible if you are truly interested but cannot make the said dates)

Location:

Virtual Reality Lab 3.46, Brooks Building, M15 6GX, Manchester Metropolitan University

FOR MORE INFORMATION:

Please email sandaru.n.weerasinghe@stu.mmu.ac.uk

Department of Natural Sciences, All Saints Campus, Manchester Metropolitan University, Manchester M15 6BH

Appendix B – Participant Consent Form

Participant Identification Number:

CONSENT FORM

Title of Project: **Rethinking Streetscapes: exploring spatiotemporal variation in the fear of crime using virtual reality**

Name of Researcher: **Sandaru Weerasinghe**

1. I confirm that I have read the information sheet dated .... for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my legal rights being affected. ☐
3. I understand that relevant sections of the data collected during the study, may be looked at by individuals from regulatory authorities or external organisations, where it is relevant to my taking part in this research. I give permission for these individuals to have access to my records. ☐
4. I understand that the information collected about me will be used to support other research in the future, and may be shared anonymously with other researchers. ☐
5. I agree to take part in the above study. ☐

______________	______________	______________
Name of Participant	Date	Signature
______________	______________	______________
Name of Person taking consent	Date	Signature

Appendix C – Follow-up Survey Questionnaire

Rethinking Streetscapes: exploring spatiotemporal variations in the fear of crime using virtual reality

Protocol for semi-structured interviews about fear of crime in urban alleys: Follow-up questionnaire

(If at any point in the questionnaire you feel uncomfortable in answering, please say so)

1. Age: ……………

2. Gender:

Female	Male	Other	Prefer not to say

3. Do you have experience of being a victim of crime when you were using urban space?

Yes	No

4. If yes, what type of crime were you a victim of?

Being mugged and robbed	
Physical attack	
Sexual assault	
Other	
Prefer not to say	

Other, please specify: ……………………………………………….

5. Have you been a victim of crime in an alleyway in particular?

Yes	No

6. If yes, what type of crime were you a victim of?

Being mugged and robbed	
Physical attack	
Sexual assault	
Other	
Prefer not to say	

Other, please specify: ……………………………………………….

7. Would you typically use an alleyway to get from one place to another?

Yes	No

8. What type of crime risks would you be concerned about in an alleyway?

Being mugged and robbed	
Physical attack	
Sexual assault	
Other	

Other, please specify: ……………………………………………….

9. Walking through an alleyway, how worried are you about being mugged or robbed?
(1 = never, 2 = rarely, 3 = sometimes, 4 = often, 5 = always)

	1	2	3	4	5
Daytime					
Night					

10. Walking through an alleyway, how worried are you about being sexually assaulted?
(1 = never, 2 = rarely, 3 = sometimes, 4 = often, 5 = always)

	1	2	3	4	5
Daytime					
Night					

11. Walking through an alleyway, how worried are you about being physically attacked by strangers?
(1 = never, 2 = rarely, 3 = sometimes, 4 = often, 5 = always)

	1	2	3	4	5
Daytime					
Night					

12. Walking through an alleyway, how would the presence of following environmental cues increase your perception of criminal risk?

(1 = no criminal risk (never), 2 = low criminal risk (rarely), 3 = moderate criminal risk (sometimes), 4 = high criminal risk (often), 5 = very high criminal risk (always)

Scenario		**Daytime**	**Night**
End visibility (Visual permeability)	Curved alleyway (no end visibility)		
Visual entrapment	No open sky (tunnel alleyway)		
Human presence	Teenagers / men in dark clothes / hoodies hanging around in the alleyway		
	No presence of people		
	People walking through the alleyway		
Maintenance	Vandalism, graffiti or other deliberate damage to properties, walls or parked vehicles in the alleyway		
	Rubbish or litter lying around		
Street lighting	Poor lighting (little to no street lighting)		

13. Walking through an alleyway in real life, would you repeatedly look at an environmental cue as opposed to in a virtual environment? (For example, moving people)

Yes	No

Why? ……………………………………………………

14. Assessment of results – significance of environmental cues (weighting of likelihood of criminal risk) mismatches, if any?

Scenario		**Daytime**	**Night**
End visibility (Visual permeability)	Curved alleyway (no end visibility)		
Visual entrapment	No open sky (tunnel alleyway)		
Human presence	Teenagers / men in dark clothes / hoodies hanging around in the alleyway		
	No presence of people		
	People walking through the alleyway		
Maintenance	Vandalism, graffiti or other deliberate damage to properties, walls or parked vehicles in the alleyway		
	Rubbish or litter lying around		
Street lighting	Poor lighting (little to no street lighting)		

Protocol for semi-structured interviews about the VR application and experimental study: Follow-up questionnaire

1. How easy and smooth was the navigation?
(1 = very poor, 2 = poor, 3 = fair, 4 = good 5 = excellent)

1	2	3	4	5

2. How convenient was the motion speed / speed of navigation?
(1 = very poor, 2 = poor, 3 = fair, 4 = good 5 = excellent)

1	2	3	4	5

3. How would you rate the level of realism?
(1 = very poor, 2 = poor, 3 = fair, 4 = good 5 = excellent)

1	2	3	4	5

4. How would you rate the user-friendliness of the VR application?
(1 = very poor, 2 = poor, 3 = fair, 4 = good 5 = excellent)

1	2	3	4	5

5. How would you rate the lab space for this particular experiment?
(1 = too small, 3 = perfect space, 5 = too big)

1	2	3	4	5

6. How comfortable were you during the experiment?
(1 = never 2 = rarely, 3 = sometimes, 4 = often, 5 = always)

1	2	3	4	5

7. How would you rate the level of immersion and sense of presence in the environment?
(1 = very poor, 2 = poor, 3 = fair, 4 = good, 5 = excellent)

1	2	3	4	5

8. Did you feel dizzy at any point during the experiment?
(1 = never 2 = rarely, 3 = sometimes, 4 = often, 5 = always)

1	2	3	4	5

9. Suggestions or recommendations?

****If you feel that you need to talk to someone, please take a look at the contact information sheet of potential organisations both within the university and local and national level.**

Appendix D –URLs for scenarios (walkthrough of one participant across five scenarios)

Scenario 01: https://youtu.be/wm3VvZxUHR0

Scenario 02: https://youtu.be/NRK72AuVYwQ

Scenario 03: https://youtu.be/Dm6hE96oKPw

Scenario 04: https://youtu.be/r4rBSAmlMBE

Scenario 05: https://youtu.be/eq44wDE1zTs