



The use of XR technology in criminological research: a scoping review

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Abstract

Objectives Criminology has begun to use virtual reality (VR) as a tool to understand criminal behaviour. There have been many advances in VR that open up the possibility of novel research designs, in addition to the inclusion of augmented reality (AR) as a potential research tool. A review of the efficacy of the use of AR and VR (together known as XR) within criminology is now required to guide the further development of this field.

Methods We employed a scoping review, which after screening, incorporated 41 papers for review.

Results We uncovered three important characteristics for the papers: research topics for which XR is employed, the prominence of VR research over AR and XR and methodological rigour. VR is mostly employed for creating scenarios, in particular in research on memory and aggression. Studies vary greatly in their use of interaction within VR scenes, description of technical specifications and sample sizes.

Conclusions Despite the identification of some methodological limitations in the existing literature, VR has found its place in criminological research. With technological advancement, AR may also find its place in the future, allowing for the ongoing development of research applications. Creating comprehensive guidelines on how to use XR technology in criminology remains necessary.

Keywords VR · AR · XR · Criminology

Virtual reality (VR) is a relatively new addition to our toolbox for studying crime. With VR simulations, we can place a recipient in any virtual world that we can create and thus expose them to any crime-related scenario that we desire. For example, we could place burglars in virtual neighbourhoods to see how they scout such

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neighbourhoods or have people view mock crime scenarios in VR and subsequently interview them as witnesses. Using VR, we can simulate the context of any crime with high experimental control (Blascovich et al., 2002; Mania & Chalmers, 2001; van Gelder et al., 2017) and watch behaviour as it unfolds (van Gelder et al., 2014). van Gelder et al., (2014) argued that criminologists can use VR in criminological research not only to improve existing methods of data collection, but also to facilitate studying phenomena that cannot be studied otherwise.

Since van Gelder et al., (2014) argued for using VR as a research method, there has not been a comprehensive overview of the state of VR in criminological research, or of what lessons can be learned from the research that has been undertaken to date. Importantly, there have been numerous developments within VR that allow for even more opportunities to discover additional information within virtual environments (Vasser & Aru, 2020). Furthermore, immersive virtual worlds could now also be viewed through smartphones and glasses that place virtual worlds on top of the actual world (Liao et al., 2020), providing a range of new immersive environments and techniques that can be used to study crime.

In the current study, we will review criminological research papers that have employed VR and AR to study crime. We aim to identify specific fields within criminological research that have been particularly progressive in employing immersive environments to study crime and assess examples of good practice in studying criminology using AR or VR. We will employ a scoping review to achieve these goals.

Understanding crime and criminals through immersive virtual environments

Studying crime can be a daunting task, and a wide variety of methods have been employed to help us understand this topic (Dezember et al., 2021). There is increasing evidence that immersive technologies, in particular virtual reality (VR), are an excellent way to address problems that have hindered our understanding of crime within the criminological field and to study phenomena that are hard to study due to ethical or practical reasons (van Gelder, 2023). With VR, you can create any world possible via a computer-generated environment (Brey, 2020). This virtual environment can be viewed through stereoscopic VR glasses that allow you to view the environment as you would in real life (Fox et al., 2009) and transform you into a different world (Brade et al., 2017).

It has been a decade since van Gelder et al., (2014) argued for adding VR to our criminological research toolbox. They highlighted how VR allows researchers to study phenomena that are ethically, practically or financially problematic to study, by recreating the situations within VR. The context of any scene can be simulated in a realistic way (Mania & Chalmers, 2001; van Gelder et al., 2017) while maintaining high experimental control (Blascovich et al., 2002; Fox et al., 2009).

van Gelder et al., (2014) provided an overview of the state of VR at the time and assessed existing applications. VR had been used as an innovative way to address the tendency for offenders to focus on short-term gain rather than consider longer-term consequences, by exposing individuals to their future selves

(an age-progressed avatar) in VR (van Gelder et al., 2013). Other research attempted to study burglary in action by having burglars break into a virtual and a real house, observing their behaviour in both (Nee et al., 2015). No differences emerged between the way the virtual or real houses were burgled—pointing towards the overlap of behaviour shown in the real world and its equivalent virtual world. Lastly, VR was used to test the impact of the environment on decision-making, such as the impact of signs of public disorder on the perception of a neighbourhood (Toet & van Schaik, 2012). VR proved its potential value in being able to study criminal behaviour as it was unfolding, in environments with full experimental control with a remarkable similarity between behaviour shown in the virtual environments and the real world (van Gelder et al., 2014).

Since the initial viewpoint paper by van Gelder et al., (2014), it seems however that researchers have not capitalised on the possibilities of VR as was hoped. A literature review (Cornet & Van Gelder, 2021) looking at the use of VR for the criminal justice domain indicates that current examples are relatively limited. They believe that the most prominent reasons lie in practical challenges, namely costs associated with VR environments, experienced discomfort of recipients of VR and potential psychological and emotional side effects of specific VR experiences. However, the review of Cornet & Van Gelder, (2021) only focuses on the criminal justice system. Recently, van Gelder, (2023) wrote an essay discussing the literature using VR in criminological contexts and related fields. The conclusions of this essay were that criminologists have not yet seized the opportunity en masse of using VR, even though the field could benefit greatly from observing and measuring behaviour as it is currently unfolding using virtual environments. It seems however that we lack a structured overview of what criminological research has capitalised on the use of VR and the features of such studies. Insight into these fields and features would provide us with better guidelines on when to use VR in criminological research and what we can learn from the success stories (or failures).

It is important to create a systematic overview of VR used in criminological research, as virtual environments are always evolving. In the last decade, another form of virtual environment has emerged: augmented reality (AR). With AR, you see the world around you as you normally would, but visual information is overlaid on top of real-world experience (Liao et al., 2020). That is, the user still sees the real world, but other digital images are now also visible. This visual information can be displayed via a mobile phone or special AR glasses. The most famous example of AR is most likely Pokémon Go, in which players view the real world via a mobile device, and Pokémon characters appear on screen as if they are in the real world. Another example is apps that allow you to see what a fresh new layer of paint in a different colour would look like in your house when you point your phone to a wall that needs redecorating.

While VR creates whole new virtual environments in which recipients are transported, AR allows us to blend the existing reality with a new reality in which the recipients see the real world with an additional layer (Xue et al., 2021). Both AR and VR fall under the umbrella term of extended reality (XR), and when AR and VR are combined as methods, we speak of MR (Ratcliffe et al., 2021). AR and MR

provide another tool in our toolbox as criminologists, but it is unclear if AR or XR is actively being used in this domain.

To our knowledge, no systematic review currently exists that looks at the state of the use of immersive environments (VR, AR, MR or XR) for criminological research. This would allow us to see in which fields within criminological crime research XR has been successfully applied and the methodological rigour and features of these studies (e.g. technical and content requirements associated with effective simulation development). This information combined will help us identify good research practices and create guidelines for the use of XR within criminology that are currently lacking. A critical review of the use of XR in criminology is essential to inform the further development and advocacy of such methodological approaches in the future.

The current study

In the current study, we aim to provide an overview of the state of criminological research employing XR technology. We aim to identify the areas of criminological research in which XR is featured most prominently, how XR technology is employed in these studies and what best practices arise in creating immersive environments. We address these questions via a scoping review. Findings will be used to provide an overview of criminological research using XR and to make recommendations for how XR technology can be used to further shape the criminological research agenda.

Methods

We employed a scoping review rather than a systematic review for the current study as the aim was to establish a broad sense of the use and application of XR technology within criminological research. A scoping review allows for the inclusion of research regardless of research design and approach, enabling an iterative process for the inclusion criteria (Arksey & O'Malley, 2005). We employed a search strategy to find academic papers published in English with a focus on the use of XR within criminological research. We developed keywords to encompass virtual reality, augmented reality and mixed reality, as well as keywords that reflect research and experiments. We refined the search string until the results were as comprehensive as possible. To ensure we would capture literature not only published in social science journals, we searched five academic databases: Scopus, Web of Science, PsycINFO, Pubmed and ACM DL. Table 1 displays the search strings employed for each database.

Within scoping reviews, inclusion and exclusion criteria develop iteratively during the process of screening articles. Our inclusion criteria remained unchanged. Papers were required to (i) focus on a topic within criminology, (ii) include the use of VR, AR or XR and (iii) be focused on research. Initial exclusion criteria were (i) a focus on teaching and training, (ii) a scope beyond

Table 1 Search string for scoping review

Database	Search string	Hits
Scopus	TITLE-ABS-KEY ("virtual reality*" OR "augment* reality*" OR "mixed reality*" AND TITLE-ABS-KEY (criminology OR ((crim* OR forensic OR legal) W/5 (research* OR stud* OR investig* OR experiment* OR test* OR examin*)))	340
Web of Science	TS=("virtual reality*" OR "augment* reality*" OR "mixed reality*" AND TS=(criminology OR ((crim* OR forensic OR legal) NEAR/5 (research* OR stud* OR investig* OR experiment* OR test* OR examin*)))	130
PsycINFO	TI ("virtual reality*" OR "augment* reality*" OR "mixed reality*" AND ("criminology OR ((crim* OR forensic OR legal) NEAR/5 (research* OR stud* OR investig* OR experiment* OR test* OR examin*)) OR AB ("virtual reality*" OR "augment* reality*" OR "mixed reality*" AND ("criminology OR ((crim* OR forensic OR legal) NEAR/5 (research* OR stud* OR investig* OR experiment* OR test* OR examin*)) OR KW ("virtual reality*" OR "augment* reality*" OR "mixed reality*" AND ("criminology OR ((crim* OR forensic OR legal) NEAR/5 (research* OR stud* OR investig* OR experiment* OR test* OR examin*))	10
PubMed	("virtual reality*" OR "augment* reality*" OR "mixed reality*" AND (criminology OR ((crim* OR forensic OR legal) NEAR/5 (research* OR stud* OR investig* OR experiment* OR test* OR examin*)))	137
ACM/DL	Abstract: ("virtual reality" OR "augment* reality" OR "mixed reality") AND Abstract: (criminology OR (crim* OR forensic OR legal) AND Abstract: (research* OR stud* OR investig* OR experiment* OR test* OR examin*))	14

refers to the wildcard character to account for multiple endings in databases. For example, virtual reality will return virtual reality and virtual realities

criminological research and (iii) technical papers that only talk on developing XR environments. It became clear that we had to refine our exclusion criteria to contain only papers that include empirical data, as there were multiple view-point papers that only addressed the potential of (mostly) VR for criminological research. We also had to exclude studies that were not using VR, AR or XR but rather used non-immersive virtual environments. Lastly, we also had to exclude papers that focussed on behaviour within virtual environments. This means that XR was not employed as a research method in those studies, which is the objective of the current study. Table 2 summarises our inclusion and exclusion criteria.

One author (IvS) screened all titles and abstracts of the identified articles. After excluding papers that were clearly irrelevant, the second author (AM) reviewed the excluded articles through a random screening of 50 papers. Furthermore, both authors discussed three papers that were marked as doubtful in the abstract screening process. The full screening was done by one author (IvS), after which all articles were discussed by both authors.

The search within the databases resulted in 631 papers. Of these 631 papers, 141 proved to be duplicates. After the exclusion of these papers, 490 papers were screened for title and abstract. The first author took the lead in screening the titles and abstracts. Articles at this stage would only be excluded if it was clear the paper did not fall into the scope of the review. This title and abstract screening resulted in 391 removed papers and 99 papers kept for full screening. Based on the inclusion and exclusion criteria, the papers were read fully. When there were doubts on when to exclude an article at the full-screening stage this was discussed within the research team. Of the 99 papers, 66 papers were excluded for the following reasons: not being able to access the paper (4), paper not written in English (3), lack of empirical data (17), scope not in criminological (4), lack of use of XR methodology (11), focus on training rather than research (3), XR as object of research but not methodology (4) or technical papers (20). This resulted in 33 included papers. Finally, through a manual search of the references of the papers included in the full screen, 8 more papers were identified as relevant to the review. In total, the final number of papers was 41. Figure 1 summarises the screening process.

Table 2 Inclusion and exclusion criteria for papers

Inclusion criteria	Exclusion criteria
Use of VR, AR or XR	Focused on teaching and training
Focus on XR in research	Scope beyond criminological research
Focus on criminology	Focus on developing XR environments
	Study of behaviour within virtual environments (e.g. the Metaverse) rather than using XR as a methodology
	Lack of empirical data
	No use of VR, AR or XR but virtual environments
	Not written in the English language

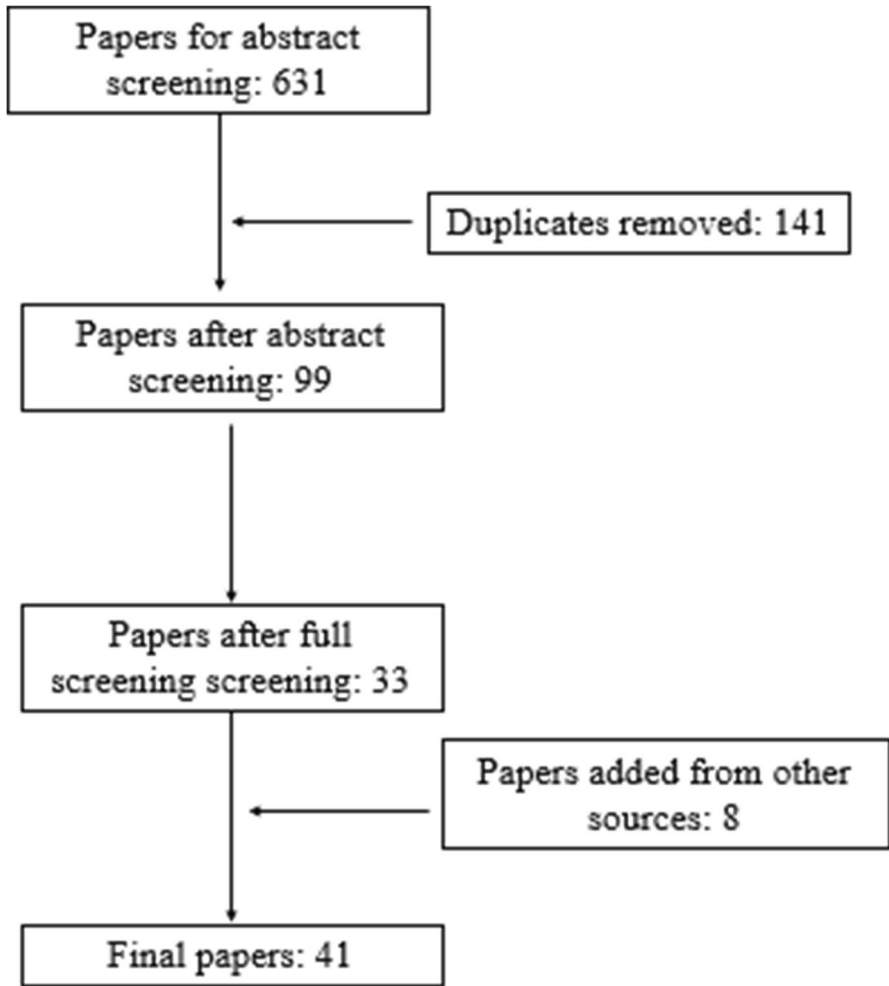


Fig. 1 Overview of papers included in scoping review

Results

The aims of the current study were to understand the scope of XR within criminological research and to synthesise how XR is employed within the criminological research field. For this, we chose to use a narrative synthesis rather than a statistical synthesis. We uncovered three important characteristics of the papers: research topics for which XR is employed, the prominence of VR research over AR and XR and the features of employed XR (a list of all papers and their characteristics can be found within Table 3 in the Appendix).

Research topics and XR

In reviewing the research topics that had been studied using XR technology, 10 main areas featured prominently. These were aggression, burglary, bystander effect, understanding child abuse, CPTED (crime prevention through environmental design), future self, lie detection, memory, treatment of victims of crime and a category of “other” encompassing unique XR studies. We will discuss these areas in order of the prevalence of studies.

Memory

We identified eight papers that used VR as a means to understand the memory of criminals, jury members, witnesses and the police. Here, VR is used mostly to create mock scenarios to understand eyewitness memory. Kim et al., (2014) created two VR environments (a meat market and a classroom) in which arousal and (un) expected events were varied, to understand the impact of context on the memory of potential victims. Nyman et al., (2020) let participants view threatening or non-threatening 2D or VR videos from a first- or third-person perspective, to subsequently have participants identify suspects in a photograph line-up. Bailenson et al., (2008) on the other hand used VR after a staged crime to see its impact on witnesses identifying suspects, experimenting with the set-up of the line-up of witness viewpoint, distance and angle in VR. Timmer et al., (2023) took a different approach, using VR not for a mock crime event, but as a virtual context reinstatement method for a mock crime. Participants participated in a group experiment in which a mock crime happened and were asked later on to revisit the crime scene, either in VR, at the actual crime scene or in their minds alone.

Two articles from Reichherzer et al., (2018); Reichherzer et al., (2021) focus on the use of VR to understand the memory of jury members and how the display of information impacts their decision-making process. Participants were asked to serve as a mock jury, viewing a mock crime scene in VR, via photographs or physically (Reichherzer et al., 2018). In another study (Reichherzer et al., 2021), participants listened to the opening statements of a mock prosecutor and defence attorney and subsequently viewed a crime scene either in VR or using photographs.

One paper explicitly used VR as a mock crime scene for testing memory in which participants were playing offenders. Kloft et al., (2022) aimed to establish the immediate and delayed false memory information after acute MDMA exposure. Participants saw two mock crime scenarios in VR in which they were once the eyewitness and once the perpetrator after having consumed MDMA. Another paper required that participants take the role of police officers, wearing chest-mounted cameras as they viewed a simulated theft in VR (Adams et al., 2020).

Aggression

We identified six studies that use VR to understand aggression. Terbeck et al., (2022) aimed to assess reactive violence in VR and had participants interact with a friendly or unfriendly virtual other. van Gelder et al., (2019) compared responses of

a written bar fight with the same scenario presented in VR to assess the substantial benefits of VR scenarios over written scenarios. van Gelder, de Vries, et al., (2022) expanded on the previously mentioned bar fight scenario with a different sample to further replicate the effectiveness of VR scenarios over written scenarios.

Several studies from Seinfeld et al., (2018); Seinfeld et al., (2023) and Gonzalez-Lienres et al., (2020) used VR to put an aggressor in the virtual body of their victim. This was done by placing male offenders in the body of a victim of domestic abuse (Seinfeld et al., 2018), placing male offenders in the body of a female victim or bystander (Gonzalez-Lienres et al., 2020) or male offenders in the body of a child (Seinfeld et al., 2023).

Treatment of victims

We identified six papers that focus on exploring the potential of XR to better understand the treatment of victims of crime. As these are explorations, they still fall within the scope of our review as they encompass research methodologies. We do believe however that this topic warrants its own scoping review, as treatment of victims using VR is a topic with significant impactful potential (Loranger & Bouchard, 2017).

Four of the six papers employed VR to study victims of sexual assault. Freeman et al., (2013); Freeman et al., (2014) created a VR train ride in which people who were victimised 4 weeks prior were asked to take a 4-min journey in the London underground, where they were exposed to virtual others. Cárdenas-López et al., (2015); (Cárdenas-López & De Rosa-Gómez, 2011) used VR to create virtual environments of a city within Mexico. Former victims of violence were asked to move through this environment that could potentially make them feel unsafe (e.g. crossing a narrow pedestrian bridge), while avatars looked suspicious and could be close to the participants. The aim was to see how anxiety-provoking such spaces would be for the former victims.

Lee and Cha, (2021) used an AR application that showed a virtual female via a smartphone who would instruct young women who suffer from sexual violence on reflective writing and mindfulness meditation. Loranger & Bouchard, (2017) aimed to validate a VR environment for sexual assault victims which would allow patients to be progressively exposed to sexual assault scenarios, being confronted with an aggressor in a bar who would assault them or not.

Bystander effect

In total, five studies used VR to recreate scenarios aimed to study the bystander effect. Slater et al., (2013) made use of VR to create a violent incident in a bar, in which a virtual out-group or in-group member was harassed. A similar study was executed by Hortensius et al., (2018), in which participants saw an out-group or in-group member being harassed and were exposed to a low or high cognitive load manipulation. Krauss et al., (2021) used VR to observe the bystander behaviour of college students in reaction to several scenarios involving campus violence. Jouriles et al., (2016); Jouriles et al., (2019) tested the effectiveness of bystander interventions

via VR. Using the same adolescent participants, VR was used to assess bystander behaviour at 1-week and 6-month intervals after having received an intervention to increase bystander behaviour.

CPTED

VR allows for the creation of any scene that can be imagined. As such, it is perhaps unsurprising that CPTED, a field that studies the link between features of the environment and fluctuations in criminal activity, has started to explore the potential of VR. In total, we found five studies that use XR to study CPTED. One of the first studies in our scoping review had participants walk through a series of train stations in VR (Cozens et al., 2002) to get an understanding of their perceptions of safety in these train stations. Subsequently, the authors used the technology in a similar study on fear and safety in train stations with a larger sample (Cozens et al., 2003). Noh and Lee (2019) studied the usefulness of VR simulations for CPTED research by exposing participants to a virtual urban park and compared responses of realism and safety with responses to the same park in real life. Castro-Toledo et al., (2019) showed that fear of crime can be elicited through VR by comparing experiences of a public location during the day versus at night in VR.

One exciting study in this field comes from Liao et al., (2020), the only CPTED paper that uses AR to see how people process crime information. Participants were asked to explore a metropolitan area in the USA and were given crime information via an AR application on smartphones. Pointing the camera of the smartphones on pre-indicated spots would provide information about crime in the exact location—for example, if a burglary was committed in a specific place.

Burglary

Four papers used VR to understand how burglars select houses to burgle and their behaviour within these houses. van Gelder et al., (2017) examined how 77 male students burgled a virtual house. van Sintemaartensdijk et al., (2021); van Sintemaartensdijk, van Gelder, et al., (2022); van Sintemaartensdijk, van Prooijen, et al., (2022) employed a virtual neighbourhood rather than a virtual house to study the burglar scouting process that takes place prior to the actual burglary itself, examining the effect of physical guardianship (van Sintemaartensdijk et al., 2021), symbolic guardianship (van Sintemaartensdijk, van Gelder, et al., 2022) and personality (van Sintemaartensdijk, van Prooijen, et al., 2022) on the scouting process.

Future self

Two papers used VR to confront offenders with their future selves. van Gelder et al., (2013) were the first to put participants in VR and have these participants interact with a digitally realistic version of their aged future selves. Subsequently, a study was conducted with a sample of actual convicted offenders rather than student participants (van Gelder, Cornet, et al., 2022).

Lie detection

Two papers used VR to study lie detection. Hahm et al., (2009) combined a virtual mock crime with a guilty knowledge test. Their VR mock crime scene consisted of a virtual library, and participants were asked to conceal information about lost money in the library and innocent participants who were free from concealing information. Norman et al., (2020) had participants first commit a mock crime in VR, after which they viewed this mock crime scene environment once again in VR or via photographs after which they were interrogated.

Child abuse

One paper explores the use of VR to assess deviant sexual interest, risk assessment and treatment of child abusers. Renaud et al., (2014) experimented with anatomically correct computer-generated characters in VR to assess deviant sexual preferences. Both deviant child abusers and non-deviant adult males were exposed to virtual characters that were a female adult, female child, male adult, male child and a neutral character.

Other

Two papers did not adequately fit the above-mentioned topics. Reehl and Sharma (2022) used VR to visualise data of crimes in an immersive way. They employed a VR environment in which a map of the city of Baltimore, USA, was present. Participants in the environment could click on the map, and 3D information would pop up (e.g. the number of murders within each part of the city). Clifford and White (2020) used VR as a means to elicit empathy. They wanted to see if feelings of solitary confinement could be well replicated in VR and subsequently boost empathy. A 9-min VR environment was created reflecting the first-person perspective of someone in solitary confinement.

Prominence of VR over AR

Overwhelmingly, we find that VR is used in the research identified by our scoping review. In total, 39 papers used VR to study crime and criminal behaviour, and two papers employed AR. The 39 studies mostly employ VR as a means of scenario testing: virtual worlds were created in which the user was expected to respond to the scenario. As seen in the description of the papers before, this could be a familiar setting, a whole new environment or even within a whole new body.

There is one paper that explicitly mentions AR and describes the gap between the use of VR versus AR as a research method. As specified before, Liao et al., (2020) used AR to provide people with information on which crimes had taken place in a city in the USA. The authors believe that an understanding of AR information in relation to place could become important for policymakers and

designers for preventing crime and designing space. Liao et al., (2020) firmly believe we should study the display of information via AR applications and the impact on physical space and that more AR applications studying crime will be on the rise. There is also the application used by Lee and Cha, (2021) that can be classified as AR, as a virtual other was displayed in the real world. However, the authors themselves classify this as VR rather than AR. Given that the study makes use of smartphones only and no head-mounted display to immerse the users into a virtual world without displaying the actual world, in the current study, we classify this study under AR.

Methodological rigour

To understand the methodological rigour of the papers listed in the review, vital aspects of the study were tallied: the features of the virtual environments, interactions possible within the environments and the number of participants listed in each paper.

We found that 20 papers stated that no interactions were possible within their environments. This means that participants cannot pick up items or walk around in an environment but are mere spectators to what is going on. The other 21 papers mention the interactive features of their environment. This, for example, reflects hitting or shaking another person's hand (Terbeck et al., 2022) or picking up items (van Gelder et al., 2019). There is little reflection within the papers on how the features of the environment in respect to interactions could impact their results, even though interactivity is an important factor contributing to immersion (Mütterlein, 2018).

We found that the majority of papers were unclear when it came to the setup of their research in regard to the used equipment and the program used to run the virtual environment. Of the 41 papers, we were able to determine what equipment was used and in which program the virtual environment ran for only 21 papers. In addition, 10 papers only mentioned either the equipment used (such as an Oculus or HTC VIVE) or the program (such as Unity or Unreal). In total, 10 papers made no mention at all of the equipment or program used for the virtual environment. No conclusive overview can be given of the most used program and equipment or their usability.

We also tallied the number of participants per article. One paper did not specify the number of participants. Of those that did, 17 articles tested the VR environments with under 50 participants, 12 with 50–100 participants, 4 with 101–150 participants, 3 with 150–200 participants and 4 papers with over 200 participants (see also Table 3 in the Appendix for an overview of exact participant numbers). Of the 41 papers, 5 papers could be classified as case studies and have either under 50 participants or an unspecified number of participants. That means that of the 36 papers that are listed as experimental studies or correlational papers—for which participant numbers need to be most likely over 50 in order to make comparisons—approximately 36% of the papers report participant numbers under 50.

Discussion

In this scoping review, we aimed to establish the current use and application of XR in criminological research. Findings show that in recent years, there has been an increase in studies that employ VR. Most of these studies use VR to create scenarios to understand the responses of the participants on a variety of topics. Most prominently, research in burglary and the bystander effect has capitalised on the capacity of VR to expose participants to scenarios and study their behaviour in these scenarios. With the XR framework, only a few studies apply AR, with MR being non-existent. An important finding was the extent of variety in the interactions possible within (mostly) the VR environments. In addition, few studies reported the programs and equipment used to create and expose participants to virtual environments. Participant numbers for the experiment and correlation studies were mostly over 100 participants. Nonetheless, the reviewed studies show that VR has slowly been put forward on the criminological research agenda.

The value of XR for criminological research

Undoubtedly, the current use of XR technology relies on the use of virtual over augmented or mixed reality and within this observation, the most common application is in the creation and testing of scenarios. Kozlov and Johansen (2010) argue that the written counterparts of VR scenarios, namely vignettes, will give artificial responses, arguing that the use of VR allows for the closer approximation of real-world behaviour. van Gelder et al., (2019) made a direct comparison between written vignettes by having people either see a scenario about a bar fight or read the written vignette. Participants experienced a stronger presence and higher realism and most importantly reported a higher intention to address. Testing out scenarios in VR thus appears to provide distinct benefits over written scenarios.

Using VR scenarios, we are able to adopt a more experimental approach, addressing an inherent challenge associated with criminological research (Dezember et al., 2021). VR offers the opportunity to balance a high level of experimental control with high ecological validity (Blascovich et al., 2002). It is worth noting, however, that when considering ecological validity, few papers reflect on the features of the environment they employed. The overview of simulations used in research is commonly limited to a mention of the interactive features within the environment that the participant is able to control. This is compared to inactive scenarios in which the participant is merely the recipient of the scenario without engagement. A question remains that when participants are only mere recipients of a virtual environment and cannot interact with this environment, this should be classified as VR (Rauschnabel et al., 2022).

Only Toet and van Schaik (2012) explicitly mention the need to balance high ecological validity and high experimental control to ensure the effectiveness and appropriateness of the virtual environment for experimental use. As it can be costly and time-intensive to create VR environments (van Gelder et al., 2014),

it is necessary to understand what interactive features are essential for criminological research that requires such an intensive and/or expensive development process. One practical way to support the development of simulations, and thus the ongoing use of XR, is the sharing of validated VR objects in code libraries (Vasser & Aru, 2020) which would foster standardisation and replication as well as reducing costs.

Slater and Sanchez-Vives, (2016) provide a comprehensive review of the use of VR in published research, identifying and highlighting evidence for the strengths of the use of such technologies. Notably, they warn of the need for an increased evidence base for the use of VR, and of methodological rigour in future research, citing numerous examples of research that does not sufficiently fit the authors' label of a VR-based methodology. To further assess methodological rigour, we also listed the number of participants per study. Even though this study has not listed any power analyses—and thus cannot say with certainty whether studies are underpowered—the low number of participants reported in 36% of experimental studies is a cause for concern. Underpowered studies are a threat to the field of criminology (Barnes et al., 2020), and the current results show that XR papers should report on the statistical power of their studies. A further meta-analysis can shine a light on whether or not VR studies in criminology are consistently underpowered.

Whereas VR has a considerable research base in criminological research, this is not currently the case for AR or MR. AR seems especially absent in the literature when it comes to immersive environments (Xue et al., 2021). With VR, it seems clear how it can be employed as a research method, and the case for AR or XR is less well defined. Liao et al., (2020) note that AR could be particularly useful for information presentation; however, the impact on users of displaying certain types of information (such as crime statistics in specific areas) in the physical space must be carefully considered. Establishing the potential of AR as a research method in this way, or indeed, as part of an interactive game, seems necessary before we make further investments in this as a research method. The recent launch of Apple's new AR glasses opens up greater scope and potential for further investigation of AR and XR as tools for criminological research.

We must however remain cautious with the use of XR and in particular VR when it comes to generalising behaviour within the VR environment to real-life behaviour. Vasser and Aru, (2020) warn that, while VR provides novel insights about human behaviour when experiments are well designed, we must not assume that all simulations can be guaranteed to be an appropriate proxy for real-life interactions. They provide new guidelines for VR research, in which being aware of the potential confounding effects with VR worlds on the phenomena of interest and being realistic about the applicability of the results beyond the virtual world feature prominently. Although no such guidelines exist beyond VR research, undoubtedly, such guidelines for XR research within criminology will be beneficial to the field. Based on the current review, additional guidelines would entail a thorough overview of equipment and program used and detailed descriptions of possibilities in VR and ensure well-powered studies with the intended target group. As journals have limited space to describe most of these necessary components, a case needs to be made for authors to supply such information in supplemental materials or via open science frameworks.

When more XR studies provide such information, more can be learned from the best practices, and potentially, virtual environments can be shared.

Further developing an XR framework for criminological research

One feature all studies have in common is the use of the system with one recipient. Excitingly, with ongoing developments in VR technology, it is now possible to place multiple recipients within the same virtual world (Yaremych & Persky, 2019). This opens up possibilities for future research. First, we can expand on the function of VR as a criminological research scenario method by seeing responses to actual others in VR in real time. For example, we could extend the current research on the bystander effect by testing the impact of bystander scenarios on two or more people simultaneously. Second, we can have greater control over scenarios by allowing the experimenter to enter the virtual world. Currently, participants respond mostly to avatars when social interactions are studied, in which the avatars respond with a preprogrammed script that cannot be deviated from. When experimenters can join the virtual environments, they are able to deviate from preprogrammed scripts when necessary, providing a higher experimental control. For example, when trying to understand how people respond to aggression, an experimenter who is in the same virtual environment can respond to the participants in more ways than is possible with an avatar that is programmed to respond in one of a number of ways. Lastly and perhaps most exciting is the possibility to study co-offending using VR. A considerable amount of crime takes place with co-offenders, but the way in which criminal decision-making is impacted by invested others has received little attention in research to date (van Mastrigt, 2017). The inherent benefit of VR in relation to studying behaviour in practically or ethically challenging situations (van Gelder et al., 2014) extends to the possibility of placing two offenders within one environment. For example, we can assess how burglars would decide which house to burgle, what items to take and when to exit the house. This could potentially significantly increase our knowledge of co-offending decision-making.

A small number of studies have started to explore the potential of VR in criminological research regarding memory (Adams et al., 2020; Bailenson et al., 2008; Kim et al., 2014; Nyman et al., 2020; Reichherzer et al., 2018; Reichherzer et al., 2021), most of which involve using VR to simulate a crime. One interesting avenue to expand on this research is using VR to bring people back to the scene of the crime, as is being alluded to by Timmer et al., (2023). This paper has not been published, but the preprint shows that when people are brought back to the scene of the crime (via VR, physically going back or mentally), their free and cued recall is impacted. Specifically, VR increases the amount of both free recall and the number of correct details in cued recall. If VR could be a tool for context reinstatement, this could impact witness interrogation, potentially aiding in increased recall. At the least, VR has the potential to aid those who are unable to return to the crime scene such as victims or jury members.

In this scoping review, the role of XR as a research method in criminological research has been considered. We do, however, also notice another pattern emerging.

With technological developments such as the Metaverse, we will be able to spend more time within an immersive environment. Behaviour elicited in such environments will rapidly become an avenue to study new types of criminal behaviour. Interpol states that within XR worlds, we have to think about new types of crime taking place (Karit & Howcroft., 2022). For example, terrorist attacks could be prepared by scouting the targets within immersive environments, and new kinds of cybercrime can take place. These immersive environments thus open up a new type of crime research, of which we currently only know very little.

Limitations

One limitation of the current scoping review is the inability to expand or make recommendations for best practice in the use of XR. Not enough information can be extracted from the papers to say more about levels of immersion due to the technical aspects of the program, the hardware and software used or the efforts to actually increase immersion (such as the use of ambient sound). The technical information provided in most papers is prohibitively limited, reducing confidence in the evaluation of the simulations used in the research. A systematic review of the use of specific hardware, platforms and software and the features of the programs could shine a light on this matter, and it is hoped that further papers in coming years go some way to addressing this limitation.

In this scoping review, we have separated criminological research from studies that use XR for training and rehabilitation purposes. A review based on research, training and rehabilitation could potentially have given a broader overview of the applications of XR within the field. We do believe however that the use of XR for training, education and rehabilitation all warrant their own reviews, as the use of XR is vastly different. In due time, however, these applications could be jointly studied.

Conclusion

Cornet and Van Gelder, (2021) and van Gelder, (2023) state that VR is in its infancy as a research method within criminology. In this scoping review, we hope to have provided an overview of not only the state of VR, but of XR as a whole in criminological research. We can begin to see the transformation of VR to a more established research method, of which more possibilities to understand its recipients emerge. AR within criminological research still has many steps to take to become a valuable research method, but in the coming years, we anticipate an increase in the use of AR as a research method. With the ongoing development and advancement of technological capabilities, we look forward to the publication of many innovative and illuminating criminological research papers in the future.

Appendix

Table 3 Overview of papers included in the scoping review

First author	Year	Title	XR/VR/AR	Topic	Interaction within environment*	Gear and equipment mentioned**	NR participants reported
Adams	2020	Law and (re)order: updating memory for criminal events with body-worn cameras	VR	Memory: police	0	2	97
Bailenson	2008	The effects of witness viewpoint, distance, angle and choice of eyewitness accuracy in police lineups conducted in immersive virtual environments	VR	Memory: witness	1	2	98
Cárdenas-Lopez	2015	Virtual reality PTSD treatment program for civil victims of criminal violence	VR	Treatment: victims	1	0	20
Cárdenas-Lopez	2011	Post-traumatic stress disorder treatment with virtual reality exposure for criminal violence: a case study in assault with violence	VR	Treatment: victims	1	1	1
Castro-Toledo	2019	Exploring immersive technologies to simulate fear of crime	VR	CPTED	0	0	50
Clifford	2020	Mediated representations of prisoner experience and public empathy	VR	Eliciting empathy	0	0	–
Cozens	2002	A virtual reality approach to personal safety and the design of built environment facilities	VR	CPTED	0	0	36
Cozens	2003	Managing crime and the fear of crime at railway stations—a case study in South Wales (UK)	VR	CPTED	0	0	47
Freeman	2013	Paranoia and post-traumatic stress disorder in the months after a physical assault: a longitudinal study examining shared and differential predictors	VR	Treatment: victims	0	0	106
Freeman	2014	The use of immersive virtual reality (VR) to predict the occurrence 6 months later of paranoid thinking and posttraumatic stress symptoms assessed by self-report and interviewer methods: a study of individuals who have been physically assaulted	VR	Treatment: victims	0	0	106

Table 3 (continued)

First author	Year	Title	XR/VR/AR	Topic	Interaction within environment*	Gear and equipment mentioned**	NR participants reported
Gonzalez-Liencre	2020	Being the victims of intimate partner violence in virtual reality: first versus third-person perspective	VR	Aggression	1	2	27
Hahm	2009	Detection of concealed information: combining a virtual mock crime with a p300-based guilty knowledge test	VR	Lie detection	0	2	45
Hortensius	2018	The relation between bystanders' behavioral reactivity to distress and later helping behavior during a violent conflict in virtual reality	VR	Bystander effect	1	2	29
Jouriles	2016	Predicting high-school students' bystander behavior in simulated dating violence situations	VR	Bystander effect	1	0	80
Jouriles	2019	Increasing bystander behavior to prevent adolescent relationship violence: a randomized controlled trial	VR	Bystander effect	1	0	165
Kim	2014	The influence of arousal and expectation on eyewitness memory in a virtual environment	VR	Memory: witness	0	1	97
Kloft	2022	Remembering Molly: Immediate and delayed false memory formation after acute MDMA exposure	VR	Memory: criminals	1	1	60
Krauss	2021	Adverse consequences to assisting victims of campus violence: initial investigations among college students	VR	Bystander effect	1	1	299
Lee	2021	A mobile healing program using virtual reality for sexual violence survivors: a randomized controlled pilot study	VR	Treatment: victims	0	2	34
Liao	2020	Augmented criminality: how people process in situ augmented reality crime information in relation to space/place	AR	CPTED	1	2	57
Loranger	2017	Validating a virtual environment for sexual assault victims	VR	Treatment: victims	0	2	30

Table 3 (continued)

First author	Year	Title	XR/VR/AR	Topic	Interaction within environment*	Gear and equipment mentioned**	NR participants reported
Noh	2019	How useful are virtual reality simulations to the field of crime prevention through environmental design? A case study	VR	CPTED	0	1	30
Norman	2020	Caught virtually lying - crime scenes in virtual reality help to expose suspects' concealed recognition	VR	Lie detection	0	1	128
Nyman	2020	Eyewitness identifications after witnessing threatening and non-threatening scenes in 360-degree virtual reality (or 2D) from first and third person perspectives	VR	Memory: witness	0	2	37
Reehl	2022	Data visualization of crime data using immersive virtual reality	VR	Data visualisation	1	2	7
Reichherzer	2018	Narrative and spatial memory for jury viewings in a reconstructed virtual environment	VR	Memory: jury	0	1	37
Reichherzer	2021	Bringing the jury to the scene of the crime: memory and decision-making in a simulated crime scene	VR	Memory: jury	0	1	30
Renaud	2014	Using immersive virtual reality and anatomically correct computer-generated characters in the forensic assessment of deviant sexual preferences	VR	Child abuse	0	1	64
Seinfeld	2018	Offenders become the victim in virtual reality: impact of changing perspective in domestic violence	VR	Aggression	1	0	39
Seinfeld	2023	Domestic violence from a child perspective: impact of an immersive virtual reality experience on men with a history of intimate partner violent behavior	VR	Aggression	1	0	50
Slater	2013	Bystander responses to a violent incident in an immersive virtual environment	VR	Bystander effect	0	2	40
Terbeck	2022	Assessing reactive violence using immersive virtual reality	VR	Aggression	1	1	116
Timmer	2023	The virtual crime scene	VR	Memory: witness	0	2	98

Table 3 (continued)

First author	Year	Title	XR/VR/AR	Topic	Interaction within environment*	Gear and equipment mentioned**	NR participants reported
van Gelder	2013	Vividness of the future self predicts delinquency	VR	Future self	0	0	67
van Gelder	2017	Virtual burglary: exploring the potential of virtual reality to study burglary in action	VR	Burglary	1	2	77
van Gelder	2019	The virtual reality scenario method: moving from imagination to immersion in criminal decision-making research	VR	Aggression	0	2	153
van Gelder	2022a	Interaction with the future self in virtual reality reduces self-defeating behavior in a sample of convicted offenders	VR	Future self	1	2	24
van Gelder	2022b	Personality pathways to aggression: testing a trait-state model using immersive technology	VR	Aggression	0	2	176
van Sintemaartensdijk	2021	Mere presence of informal guardians deters burglars: a virtual reality study	VR	Burglary	1	2	353
van Sintemaartensdijk	2022a	Assessing the deterrent effect of symbolic guardianship through neighbourhood watch signs and police signs: a virtual reality study	VR	Burglary	1	2	353
van Sintemaartensdijk	2022b	Personality and burglary: a virtual reality study	VR	Burglary	1	2	353

*0 = no, 1 = yes; **0 = no, 1 = partially, 2 = yes

Data availability The datasets generated during and/or analysed during the current study are available in the Open Science Framework repository [<https://osf.io/xakt9/>].

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