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Linking virtual reality, architecture, and crime prevention for educational purposes

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Abstract: This paper presents selected links between the complex fields of architecture, use of virtual reality (as a part of computer science), and their potential in helping tackle crime. The presented information sets a general background for the development of a put forward prototype of new immersive learning experience to provide deeper understanding of CPTED concepts to enhance the traditional curriculum and the overall retention of knowledge. In architecture, better computer technology raises the stakes. Architecture's side of communicating ideas and managing information has been reflected in BIM. Technology is one component of larger social, economic, and business revolutions that will continue to have a substantial impact on the markets in which architects deliver services. Technological progress enables blurring the boundaries between reality and the virtual world. It is a source of inspiration and some freedom in architectural design. The theory of education is also influenced by new technologies. There are scientific studies suggesting learning in virtual reality may be more efficient than in the real world. Current VR systems provide new features for perceptual expansion, for creative construction, and for unique social interactivity. There are now hundreds of university architecture programmes with VR and AR labs all over the world. We have also changed the way of designing of and thinking about our cities, including safety. The global nature of crime has brought international cooperation in the field of prevention, one example being the CPTED security concept. New visual stimuli, such as VR, may broaden our understanding of housing design, burglary risk and CPTED, and help prevent crime. VR has also pedagogical promise, as it can be used not only to assess hypothetical environments, but also to track, shape and affect subjects' thinking towards them. There are not many practical studies on the use of VR for this purpose, which points at a niche for more research to be conducted in this area.

Keywords: virtual reality, architecture, crime prevention, security, CPTED, CAAD, BIM, visualization, education

INTRODUCTION

Virtual reality (VR), *'the popular expression for what is generally referred to in the technical field as virtual environment'* (Stuart, 1996, p. 249), is a methodology originated in informatics, optics, and robotics (Jolivalt, 1995, p. 3). The term was used for the first time (in the context) by the CEO of California-based VPL Research Inc., Jaron Lanier (Stuart, 1996, p. xxviii), in the 1980s (Whyte, 2002, pp. 2, 15). The term cyberspace, which is frequently used as a synonym for VR in American technical literature, often defined as a space which spreads in another world of a computer, appeared for the first time in 1984 in Neuromancer, a science-fiction novel by William Gibson (Jolivalt, 1995, p. 107, 108). *'Although some techniques of VR were already explored in the late 1960'ies, it became a broadly known technology (in) 1980'ies.'* (Achten, 2007, p. 66) Virtual environments (VEs) require knowledge of various disciplines like mechanical, electrical, optical, and acoustical engineering, human factors, perceptual psychology, and computer science (Stuart, 1996, p. xix). Virtual reality has its foundations in computer graphics (Sobota, 2013, p. 3). At the end of the 1960s, a computer scientist, regarded as a pioneer of computer graphics (Aukstakalnis, 2017, p. 9), Ivan Sutherland demonstrated a new possibility that had to wait for about 30 years so that the *'modern technology could support effective and useful virtual reality systems.'* (Earnshaw, 1995, p. xxi) This creation was a pioneering VR system including the use of an HMD. It was quite primitive and heavy (Lanier, 2017, pp. 42, 192, 193). The original conference paper is available in Sutherland, 1968. There is a long history of further development in this area, especially with regard to the other devices available up to present, which is not the focus of this paper. The older references in this paper are still relevant today, since the basic principles of VR stay the same.

What needs to be highlighted is that VR users are placed in a completely other place that occludes the natural surroundings (Tustain, 2018, p. 155), *'VR is an alternate computer-generated world that responds to human interaction'* (Pérez Negrón, 2020, p. iii) and *'the virtual world is a digital representation of the real world'* (Tolnay, 2011). The user is necessarily immersed in the scene through special glasses and normally also headphones and is perceptually isolated from reality in a 360° view. Some interaction is needed (Whyte, 2002, p. 4). A typical classification of VR is desktop (non-immersive), augmented (semi-immersive), and immersive VR (IVR) (Rangel Bernal, 2020, pp. 3, 4; Pérez Negrón, 2020, p. 13). Technically, immersion is related to the input and output devices. In VR for desktops, both worlds may be interacted with at once with the use of a keyboard, a monitor, a mouse, or a game controller. For augmented VR, the display is different (often a head-mounted display, a cave automatic virtual environment, possibly a data glove), and the reality is combined with computer graphics. IVR is *'an electronic simulation in which perspective images are generated in real time from a stored database corresponding to the position and orientation of the head of a user, who observes the images on a head mounted display, and in which three-dimensional sound cues are provided as well as a means for interacting with objects in the database.'* (Latham, 1995, p. 71) In IVR, one can interact solely with the VE. *'The more common input devices for IVR are the data glove and for the display, the HMD (...). Nevertheless, the users' immersion feeling can be attached to other factors, such as their willingness to believe that the virtual environment is real.'* (Rangel Bernal, 2020, pp. 3, 4) This all is illustrated in Fig. 1. Fig. 2 further sets VR into the full spectrum of reality, showing differences, which will be important to comprehend later in the text.

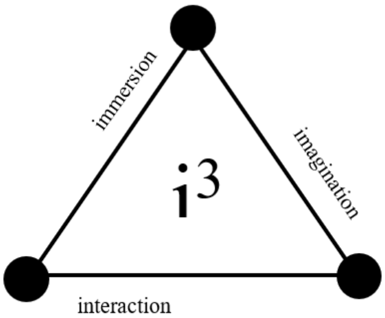

Fig. 1. Triangle of Prof. Grigore Burdea from the Rutgers University, USA, explaining three foundations of VR. (Source: Jolivalt, 1995, pp. 6, 7; redrawn by Lucia Benkovičová)

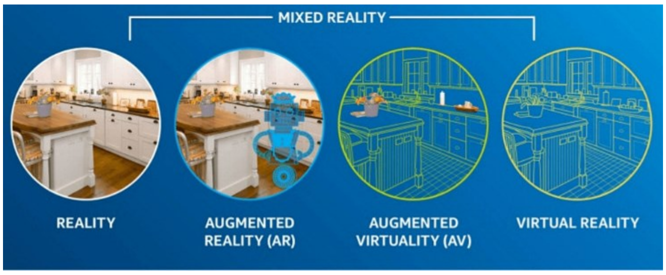

Fig. 2. Virtuality continuum introduced by Paul Milgram and Fumio Kishino in 1994. AR and VR are completely different in terms of their goals and ways of delivering the experience to the user (Elkoubaiti, 2018). (Picture source: Nova, 2018)

USE IN ARCHITECTURE

Simulations and visualizations

Peter Kamnitzer, head of the Urban Lab at the University of California in Los Angeles, USA, used an originally lunar mission simulator to create an interactive city environment. The joint project of UCLA, NASA, and General Electric was documented in a film titled City-Scape (1968; Fig. 3). *'This was the first time a simulator has been used to explore a digital model of a city. It is a surprisingly early example of the use of digital simulation techniques for general-purpose, interactive, spatial exploration.'* (McGreevy, 1993, p. 165) Kevin Hussey and his team from Jet Propulsion Laboratory later explored a digital 3D model of Los Angeles in California. *'They used a single Landsat picture and digital elevation data from the Defense Mapping Agency. They generated more than 3000 perspective images from the digital model and produced an animated virtual flight over the area.'* (McGreevy, 1993, p. 179)

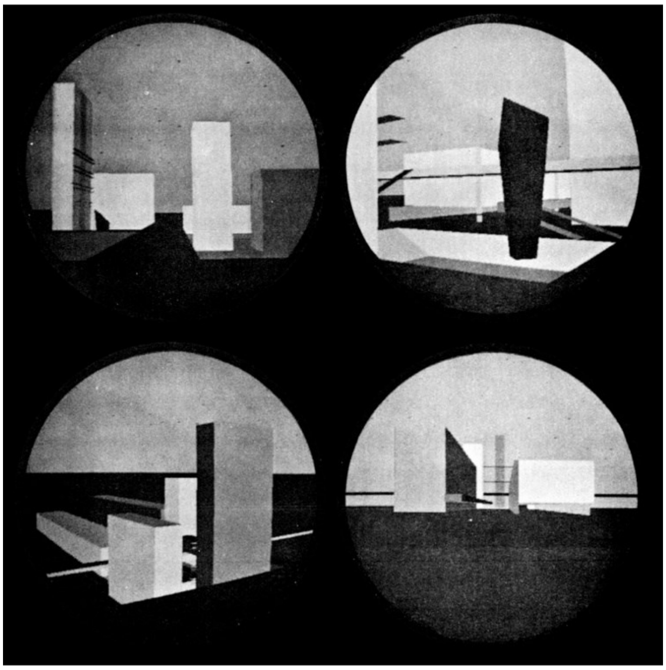

Fig. 3. Demonstration of the visualization subroutines of INTU-VAL, an online computer graphic program for iterative design and evaluation, in City-scape, an experimental film both by Peter Kamnitzer, 1966–1968. (Source: picture from UCLA Architecture and Urban Design Special Collections; published in Roth, 2019)

In 1995, a relatively few people required great realism and speed (Wyvill, 1995, p. 43). *'The quality of computer visualization–both in terms of model-building ease and image realism–is continually improving.'* (Sanders, 1996, pp. 10, 11) This is still true in 2022. Once powerful computing hardware became more available, visualization started to have a competitive edge in many disciplines. It can be regarded as a part of a natural evolution in the whole computer industry. *'The overall computer graphics market has always been characterized by rapid growth and rapid changes.'* Prices getting lower and the increasing capabilities have had a principal impact on the market. Many disciplines overlap significantly. For instance, the visualisation market is an important multimedia component, while multimedia is also often used in graphics presentation, animation merges with science and multimedia, visualisation is a part of VR and so on. *'Texture mapping, for example, allows the users to apply different textures to design variables such as car interiors and building structures and gives them the highest level of realism possible.'* (Jern, 1995, p. 343) *'... indirect illumination substantially contributes to visual realism – in particular, for indoor environments, which are not directly illuminated by the sun.'* (Schmalstieg, 2016, p. 216)

'One of the best ways to help someone visualise a computer model is to make the model move. Well-choreographed animations, in fact, are one of the most compelling forms of digital media available to the architect. (...) The fluidity of the motion depends on how fast the individual frames are displayed and the amount of motion.' (Sanders, 1996, p. 174) Interaction is affected by the frame rate (...) and the system latency (Whyte, 2002, p. 20). The presence quality depends greatly on the fluidity of movements in a virtual world (Jolivalt, 1995, p. 22). The visual comfort is currently achieved with at least 60 frames per second (FPS), usual-

ly minimum 90 FPS. To improve realism, you need to add more of them. Resolution, refresh rate and a field of vision are also important in this regard (Jolivalt, 1995, p. 33). VR technology requires special knowledge (Sanders, 1996, p. 28). *'(...) construction of 4D-CAD models is labour intensive, and the use of virtual reality requires high skills and high investment.'* (Whyte, 2002, p. 66) VR instruments let users experience and move in 3D spaces before their physical construction. They are very useful for visualization in general and also for communicating proposed designs to the clients. (Sanders, 1996, p. 408) Despite the usefulness of advanced realism in VR for making an impression, *'there are concerns that its use might make it difficult to focus attention on the relevant issues at early stages and may make designs look fixed.'* (Whyte, 2002, p. 95) Furthermore, VR may show more than had been designed or possible, and there have also been some legal issues in this regard (Whyte, 2002, pp. 97, 118).

Arts, technology, and BIM

VR has attracted special attention in the arts community. At the beginning, practically no artists would have ever given up their traditional techniques for PCs. *'Today, that is beginning to change: the state of the art in computers had advanced far enough to have an impact and most importantly we have begun listening to the artists. Virtual reality ideas and technologies give artists new freedoms, new means of self-expression, and new ways to bring their skills to bear in the information world.'* (Wexelblat, 1993, p. 75) A PhD student of art (Maukš, 2022), a product designer graduating from the Faculty of Architecture and Design, Slovak University of Technology in 2022, who was researching the application of VR in the design process, still experienced quite a lot of trouble using VR from start to finish in his designs of motorcycles and car interiors despite being an advanced user, compared to traditional techniques used in the design process. One of the opponents of his thesis, Matej Dubiš, working in the car design industry, also said that using VR at their workplace professionally is, at least for now, also often a disappointment at the end, even though some semi-products often seem impressive on the surface to others not directly involved in the creation process. *'Although certainly not a substitute for many traditional methods, such tools are providing increasingly powerful supplements.'* (Sanders, 1996, pp. 10, 11)

In architecture, better computer technology has started to raise the stakes. It can win you a competitive advantage, help enter new market, improve value of your services, improve the work quality, or bring in new clients. (Sanders, 1996, pp. 1, 8) Software development companies also significantly push professional architects not to fall behind any new release and to buy a new product version or upgrade every year. The market moves fast, the risks are real and may be substantial. VR enables walk-through simulations before the real construction of architectural design. Other examples include, but are not limited to, areas of entertainment, games, flight simulations, CAD/CAM, CFD (computational fluid dynamics), geoscience, GIS, financial analyses, medical, graphics art or scientific visualization (Jern, 1995, p. 344). *'Consultant engineers are using virtual reality to improve their reputation for technical expertise. Construction contractors and project managers are using it to reduce the risk of coordinating spatial layout and hence increase their profit margins. Real-estate owners are using it as they can afford to spend in capital in order to save it to optimize the use of their facilities by understanding the operational logistics.'* (Whyte, 2002, p. 70)

As for the CAD, the current trend is building information modelling (BIM), which is a way of creating architectural models with semantics. *'Architecture, after all, is a business of communicating ideas and managing information.'* (Sanders, 1996, p. 10) The term started to be used in the year 2000. *'The theoretical foundation exists much longer – at least 30 years – especially in academic research, where it was referred to as the virtual, central, or shared building model.'* (Achten, 2007, p. 53) Such models contain much knowledge and enable simulations and computations of the construction, costs, thermal performance, or interior climate. Interoperable software is the Achilles heel of the industry (Aukstakalnis, 2017, p. 360). It concerns using models by everyone in the building and construction industry in the same manner regardless of the software and hardware used. This issue is being solved internationally by open standardized industry foundation classes (IFC). (Achten, 2007, p. 55)

ARCHITECTURAL SPECIFICS

'Technology is (...) one component of larger social, economic, and business revolutions that will continue to have a substantial impact on the markets in which architects deliver services.' (Sanders, 1996, p. 3) Šimkovič (2010, pp. 30, 31) writes: The use of computer technology in architecture has come to the fore around 1980s, first as virtual visions of various fantastic shapes. The term digital architecture has become an umbrella term for a wide range of such new forms. *'Social and technological change has been gradually transferred to culture and architecture, creating a new language of expression commensurate with the time.'* The development continued after the Second World War in data processing, telecommunications, mass expansion of computers, and software development, after 1990 also in new (building) materials and construction technologies originally used in the automotive and shipbuilding industries. The improved software now enables the design and realization of complex irregular and curvilinear structures, composed of many different elements. In the 1990s, the first experiments in digital architectural procedures may be observed in the studios of Frank Gehry, Peter Eisenmann, Greg Lynn, UN Studio, FOA, or dECOi. This trend has continued also after 2000, when they were used more and more frequently and significantly for instance in studios Zaha Hadid, Toyo Ito, or Coop-Himmelblau. This is already extended parametric (algorithmic) architecture with its form generated by scripts written specifically for a project.

Technological progress enables blurring the boundaries between reality and the virtual world. It is a source of inspiration and some freedom in the application of non-traditional and innovative work procedures within architectural design. *'(...) mixed reality tools are getting into everyday practice and enable a more dynamic and realistic perception of virtual space. The perception of the world is manipulated through these technologies.'* VR is undoubtedly a powerful tool for both designers and architects with a significant impact on the creation process and the exploration of new ideas. The artificial-reality (AR) world, influenced by its users, has had a transformative effect on human communication, taking it in new and unexpected directions. It enables the users to experience several scenarios and worlds in one physical space, be it of artistic, educational, or entertaining nature. (Löffler, 2015, pp. 8, 9)

Computer-aided architectural design

'There are four basic activities that an architect engages in when designing with CAAD: modelling, representing, simulating, and designing. (...) Although sketching is an important basic skill for an architect, it has not been supported much by CAAD.' (Achten, 2007, pp. 10, 36) This is now partly possible also in VR, although in a completely different form. Design activities of an architect or a design team include analyses, syntheses, simulations, evaluations, and decision making (Achten, 2007, p. 110). *'The functional requirements of architectural design tools are necessarily more demanding than those of engineers.'* (Sanders, 1996, p. 4)

When it comes to quality in the AEC industry, it comprises conformance to requirements and customer satisfaction during the entire project life cycle (Sanders, 1996, p. 9). Even though today people have high expectations for realism (Schmalstieg, 2016, p. 45), it is not always the aim of computer-aided visualization: *'Most useful three-dimensional models of architecture will always be representational, not literal. And two-dimensional abstractions will always be extremely efficient forms of communication.'* (Sanders, 1996 pp. 236, 248) Architecture is not a business of making drawings but rather of managing also different kind of information (Sanders, 1996, p. 400), which can now be seen in BIM, probably in its fullest form with the combination of virtual, augmented, or mixed reality.

City models, real estate, and design

Inspired by virtual Seattle, VR has been used by the city of Singapore for growth. It helped *'Berlin plan restorations after the wall fell, (...): These renderings of Berlin were, (...), the first virtual worlds with real-time shadows and reflections.'* It was one of the most difficult things to create an accurate computer city model also later when creating a tool for the military. (Lanier, 2017, pp. 217, 220) Virtual reality shows its usefulness also in the real estate, where it is used very strategically to save time and money *'by allowing appreciation of the details and houses, such as size, textures, colours, and materials before physically changing them. It turns out to be quite feasible in recreating the real estate in a three-dimensional (3D) animation.'* (Pérez Negrón, 2020, pp. iii, iv)

Some researchers say that VR can be used by everybody, being a generic technology or interface to all construction applications. It is certainly used for a variety of tasks. *'Some see its use as a specialist activity and, as yet, no company is using it across all functions. Virtual reality is most widely used at the later stages of design, (...)'*, especially for testing and communication of design solutions, not so much for design generation (Whyte, 2002, pp. 1, 96) This is related to using VR to verify alternative designs and processes or simulations. Further, VR use seems to have more potential in large projects and reused design (Whyte, 2002, p. 124). There have been accusations of trying to replace the real world (Wexelblat, 1993, p. 146). However, this procedure is simply a tool, like a telescope or a movie, allowing us to view the world in new possible ways. *'Virtual practices are the next best thing to being there, but no one should pretend that they are the same thing as being there.'* (Sanders, 1996, p. 408)

Architectural education

The theory of education is influenced by new technologies. There are scientific studies suggesting VR learning may be more efficient than learning in the real world. In of them (Hassenfeldt, 2020), a 20-minute lecture and a lab were tested in an immersive VR group and in a real physical group with 57 students. Their knowledge results were assessed before and after the test with the same set of questions. Although there were no significant statistical differences between the groups' results, the completion was faster in the VR setting and it has been demonstrated that *'immersive learning environments in virtual worlds can enhance and augment education'* (Dede, 2009; Alessi, 2001; mentioned in Hassenfeldt, 2020). The retention of knowledge from a VR learning experience is also present (Balsam, 2019; mentioned in Hassenfeldt, 2020) and students show motivation for using VR (Ma, 2018; mentioned in Hassenfeldt, 2020). However, part of their attraction might be attributed to the newness of the experience and some users can experience blurriness, dizziness, or other discomforts. *'While many universities are moving towards online programs, students may have a more difficult time grasping material when it is difficult to perform physical labs that can only be done in person. VR could be the solution to that, especially as headset systems become more affordable and widespread. (...) Purchasing a VR headset could be a cheaper, more feasible alternative method of teaching some topics.'* (Hassenfeldt, 2020)

Educational programs and virtual workspaces are one of the possibilities of using mixed reality (MR) in the near future (Löffler, 2015, p. 9). VR has proved to be an effective adult learning environment not just for the U.S. Air force, where it saw one of its earliest applications. *'(...) it should be kept in mind that while research has proved that people could acquire spatial knowledge from virtual environments (VE), the rate of learning and accuracy of performance is almost always inferior to a real-world performance (Lessels, 2005). This statement is supported by Witmer and Kline (1998): 'Knowledge acquired from navigating through VR models appears to be similar to, but less accurate than, the knowledge acquired from navigating through the real world.'* (Whyte, 2002, p. 45) There are some studies that assert otherwise. For example, psychologists Goldin and Thorndyke (1982) had people touring an area by bus and another group experiencing the same place by watching a film. *'Though people gained spatial knowledge from both the bus tour and the film, they had different knowledge of the area. Participants in the film group identified tour locations and could remember the sequence of locations better than those who were on the actual tour. However, (...) there were significantly more subjects in the film group who were disoriented (...).'* (Whyte, 2002, p. 40)

'Current VR systems provide new capabilities for perceptual expansion, for creative construction, and for unique social interactivity. These characteristics of VR are relevant in three areas of educational theory: experimental education, constructivism, and social learning.' (Bricken, 1993, p. 201) Moreover, VR is the most humanistic approach to information, and it enables the users to change the world into a place where it is easier to learn: *'if you turn complicated data into a virtual place, a palace you can roam or a city you can tour, your brain remembers better and notices more'*. (Lanier, 2017, pp. 55, 132, 220) The potential of VR and AR in education can be seen also in mastering core skills in various settings, learning abstract concepts in complex fields (like architecture), or experiential child learning; *'One of the earliest and most successful application realms for virtual and augmented reality systems in education is the teaching of specific, tangible skill sets.'* (Aukstakalnis, 2017, pp. 299, 300)

Architecture students are faced with an immense learning task. *'On one hand, a key objective in most university programs is the development of skills required to combine concepts of space, form, materials, function, and aesthetics in the design of large, habitable structures. On the other hand, the student must learn to accurately translate and externalize these mental concepts to communicate the ideas and design intent to others.'* (Aukstakalnis, 2017, p. 304) For this purpose, mainly sketches, CAD and physical models, plans, sections, elevations, and renderings are used with accompanying text. It is difficult to combine all of it in order to see the whole design, validate and experience all its elements before the actual construction. *'This basic visualization and externalization problem has plagued the profession for centuries and extends far beyond a modern academic setting.'* (Aukstakalnis, 2017, p. 305)

Even though nowadays we have many other tools at our disposal assisting us in the visual analysis of architectural spaces, immersive systems are *'some of the first true solutions for visualizing, communicating, and experiencing design decisions at true scale'* (Aukstakalnis, 2017, p. 305). There are now hundreds of university architecture programmes with VR and AR labs all over the world. In 2022, Faculty of Architecture and Design, Slovak University of Technology in Bratislava, Slovakia, also introduced a brand-new optional course Architecture and Mixed Reality (Fig. 4), supporting the transformative influence on many industries. This course is currently recommended to students in the 5th year of the 6-year study, while also being available to undergraduates and postgraduates. Its participants will master methods and procedures for using MR when presenting the results of architectural design using HMDs, tablets, MR and mixed media. The education aim is, in addition to more comprehensive preparation of students for the defence of their own studio and final theses, also their preparation for architectural practice and project presentations for investors, local government, professional and lay public. Compared to the education of architects abroad, in Slovakia, there is still certain lack of detail related to the issue described in the following section.

Fig. 4. Photo from the course of teaching and testing of virtual reality by architecture students, which took place at the FAD STU under strict anti-epidemic measures. The validity of presenting projects through mixed reality and the interest of students to interactively present their work at a distance has been confirmed here, as well. (Photo: Vladimír Hain, the course leader, 2022)

ARCHITECTURE ASSISTING IN CRIME ELIMINATION

General background

Criminality and violence are commonly perceived as some of the most serious dangers a human can encounter. Danger to one's health, life, property, and violation of social rules endanger basic human rights to a safe place, respect of freedoms and dignity. Losses on account of crime are enormous. Successful crime combat requires knowing the causes to be able to influence conditions which contribute to the emergence and existence of crime. It is a complex phenomenon affected by many factors. The usually-mentioned basic causes are unemployment, decline and malfunction of social control, social exclusion, anonymity of life and relationships, monotonous and untended environment, family problems, loss of identity, weakening of religious and moral values, as well as negative influence of violence in mass media. Crime is also to a considerable extent contingent on the environment where it emerges, spreads, and migrates.

Criminology distinguishes social, situational and victimization prevention. The specific issue mentioned above is mainly connected to situational prevention, which concentrates on crime, protection of public order, safety, health, life, and property. Its goal is to make criminal activities more difficult and to raise probability of offender detection. It is based on the knowledge that some types of crime appear at certain time, at some places, under certain circumstances and it is easier to change the situations by the mentioned means, including planning and regulation of physical and social environment, and thus prevent commitment of offences, than to control culprits by re-education and other social prevention measures. Its aim is to eliminate situational criminogenic factors, as much as possible. Its measures are often founded on criminological findings. Situational prevention methods are very effective in property crime prevention and the benefit is extended to health and life protection and intensification of the sense of security, especially if they are tailor-made to the structure, street, quarter, and town and possibly combined with social and victimization prevention measures. In connection with situational crime prevention, at all its levels it is possible to find many measures related to architecture (planning, lighting, fencing, access control systems, iron bars, locks, safes, alarm devices, resistant materials).

In many countries, crime prevention relies on combination of social prevention, abiding the law and designing the environment including all aspects of its design and management. Urban planning and architecture show a significant potential for crime prevention. There is a direct relation between crime and architecture of environment – its layout, quality, maintenance, and management. Urban planning and architecture provably exert influence over various types of crime and fear of it by influencing behaviour, access, choices and feelings of offenders, victims, residents, police etc. Some design features in certain situations worsen local crime problems. Quality architecture and urban design are also a preventive strategy for reducing the opportunities for committing crime.

Architecture and crime prevention also have another common characteristic feature, especially on the local level – it is the tailoring, which is one of the most important prerequisites for both to be beneficial and effective. All successful design solutions must be specified in view of the site. Successful, beneficial, and effective prevention must be designed directly with conditions of the territorial unit in mind. The focus of prevention system is on the local level. Human behaviour, particularly criminal behaviour, is inseparably conditioned by the situational context. According to a Norwegian architect Christian Norberg Schulz, the environment in architecture can be divided into physical, social, and cultural (Keppl, 2011). Safe environment in architecture can be defined from the point of view of fire safety, hygiene, and health unobjectionability. These kinds of environment fall into the category of physical environment. The topic is concerned with social environment. Safety can be defined as trust or confidence in protecting of personal belongings, property, and oneself.

The main role of architects is to create an artificial environment that provides a safe place to live – protected from climate conditions, weather, and from an enemy or intruder. The role of an architect is to incorporate the security info effective spatial and operational design, provide sightlines and access control, design proper positioning of vulnerable and reserved spaces, and through design features thoroughly coordinate safety technology and personnel. For an architect it also means to get a clear idea of the requirements, know the means, and understand the implications of each design. Security demands and desired ways of use of the structure and its environment need to be specified and taken into consideration as early as possible, optimally since the assignment. The reason is that for a town planner, architect, civil engineer, landscape architect, developer, builder, community groups and municipal corporations the most effective and least expensive way is to provide security in the early conceptual and design stages.

CPTED security concept

There are many advanced approaches to understanding and tackling crime. We have changed the way of designing of and thinking about our cities, including safety (Grogan, 2000; Montgomery 2013; mentioned in Mihinjac, 2019). *'For example, many city governments now employ Safe City plans with safety strategies and liveability indices in which they recognise the synergy between urban form, crime, and social conditions. They acknowledge that all these elements together impact safety and quality of life.'* (Mihinjac, 2019) *'Crime is a phenomenon as old as human civilization and widespread globally. The fight against crime oscillates between restriction and prevention. The global nature of crime, naturally, brings international cooperation in the field of prevention. A concrete example is the CPTED project - Crime Prevention Through Environmental Design.'* (Špaček, 2011, p. 4) Alternative terms may include Designing out Crime (DOC), Defensible Space, or Crime Prevention Through Urban Development (CPT-UD). This school of secure architecture has been tried and tested and it is well established (Armitage, 2018, pp. 286, 302). Crime and fear of it persists and is associated to significant direct and indirect monetary and social costs (Cozens, 2018, p. 64). CPTED can eliminate related security risks, vulnerabilities, as well as operation costs (White, 2014). It also deals with victimization and building a sense of community.

The CPTED movement officially emerged in the 1970s as an innovation aimed at the reduction of crime with mainly architecture, urban design (urban planning), psychology, criminology, and facility management coming together. However, a journalist Jane Jacobs addressed the issue and made some suggestions on how to make places safer already in her 1961 book titled The Death and Life of Great American Cities. Some of them include 'eyes onto the street' (Fig. 5), mix land use, community building and participation. Other books important in this regard are Crime Prevention Through Environmental Design by a criminologist C. Ray Jeffery from 1971 and Defensible Space by an architect Oscar Newman from 1972 (Fig. 6). '*From the earliest years the CPTED concept included ideas to motivate positive attitudes (later called "motive reinforcement") as well as ideas to reduce physical opportunities for crime (later called "target hardening") (Cozens, 2016)'*. (ICA, 2022) For later development of the concept see Fig. 7.

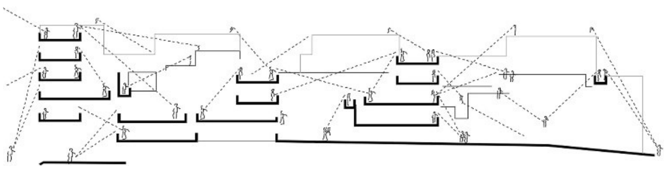

Fig. 5. Illustration of the eyes-on-the-street concept, which helps make places safer. (Source: De Jorge-Huertas, 2018)

The need for security has been a part of the development of cities. Today, security is often associated with bars and shutters on houses (not just on the ground level) and creation of private, closed, guarded enclaves surrounded by fences or walls (Fig. 6). Unfortunately, these measures may paradoxically sometimes increase the effectiveness of the attack. (Špaček, 2011, pp. 5, 6, 13) *'In terms of Maslow's hierarchy of human needs, neighbourhoods should be safe, healthy, and enjoyable. (...) It might be reasonably suggested that the Maslow needs are satisfied by all forms of CPTED.'* (Mihinjac, 2019) The CPTED philosophy is founded on the concept that *'proper design and effective use of a location's physical environment can lead to a reduction in the incidence and fear of crime as well as an improvement in the quality of life. (...) For a CPTED strategy to be effective, it must be comprehensive and integrated. (...) the goal of CPTED is to help protect a site against criminal activity while also making the same locations safe and inviting for legitimate citizens.'* (eSRX, 2022)

One of the guidelines is to structure an environment in ways that affect *'decisions that potential offenders make before committing any criminal acts.'* (Stewart, 2012) It goes hand in hand with good planning and making *'changes to the physical environment that allow for better physical and operational control of the property'*. This is not limited to creation of new environments. In fact, it is mostly used in redesign of venues using natural, mechanical, and procedural measures. *'However, you need to keep in mind that this concept may work better for new construction and remodels than for existing buildings.'* (White, 2014) Even though there are no strategies that would reduce all crime, what works best in practice is still the combination of all CPTED principles (ICA, 2022). More extensive theoretical background on CPTED can be found in my scientific monograph (Benkovičová, 2015) and on VR in my technical handbook (Benkovičová, 2021) used as a textbook by the Slovak University of Technology (based in Bratislava, Slovakia), both published mainly for Slovak and Czech readership (abstract and summary are available in English).

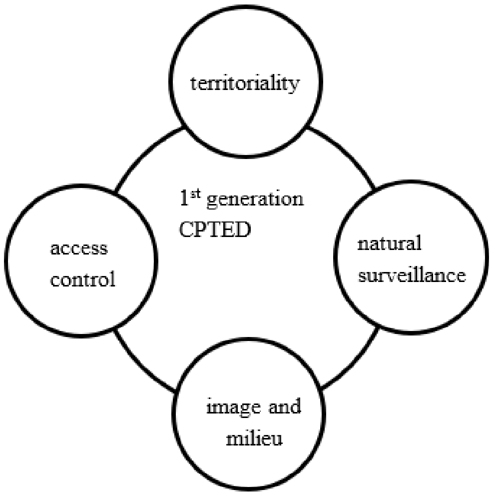

Fig. 6. First generation CPTED based on Newman's concept of defensible space as of 1972 that still constitutes solid foundations of the overall security concept. (Source: ICA, 2022; redrawn by Lucia Benkovičová)

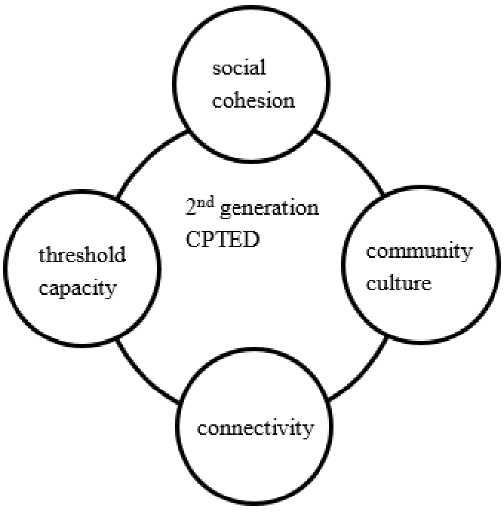

Fig. 7. Second generation CPTED, introduced by Cleveland and Saville in 1997, based on sociological research. (Source: ICA, 2022; redrawn by Lucia Benkovičová)

Fig. 8. This unusual see-through fence, located in Cambridge, UK, enables some mutual social control of the spaces that it divides. Its form further makes it more difficult to climb it over. It also serves as an easily remembered element in the wider surroundings, raising the sense of security when navigating the environment. (Photo: Lucia Benkovičová, 2013)

Exploration of VR potential for CPTED

We certainly know that VR (AR, MR) has got outstanding application both in architecture and the building (construction) industry, especially in the design process but also with respect to the final presentation (Sobota, 2013, pp. 129, 130). Cozens mentions a *'potential use of "new" visual stimuli in broadening our understanding of housing design, burglary risk and crime prevention through environmental design (CPTED)'* within exploration of imagery in VR and BIM for investigation of crime and more progressive CPTED use. These now commonly used technologies can improve our understanding of the links. He goes on to posit: *'Both VR and BIM arguably have potential use in exploring all types of crime and in enhancing the use of CPTED to deter such crimes. (...) BIM may serve as a new platform to enable additional types of CPTED design reviews (...)'*, especially for newly built structures. *'Potential contributions of VR in CPTED can go far beyond a high-quality visualization tool:'* it can be used in the design, evaluation, and training process (Noh, 2019, pp. 168, 169). There are not many practical studies on the use of VR for CPTED purposes. This fact does not diminish its usefulness and potential, and it rather points at a niche for more research to be conducted. However, *'(...) it is not an easy task to create the desired scene of reality that the researchers might want for their study.'* (Rangel Bernal, 2020, p. 8)

Be it in environmental psychology, architecture, urban design or urban planning, or criminology, it is usually necessary to study users' responses to the environment and its characteristics, which have not yet been constructed (Cozens, 2018, p. 66). The results of a study in landscape design by Seungmin Noh and Yumi Lee (Noh, 2019) showed that feelings experienced in the virtual environment generally matched with those experienced the field. When there was no match, the reasons for it were determined to be lack of details, insufficient mapping quality, and graphical issues in the VR model. This also involves higher demands on *'technical expertise in the production of the simulation for specific areas such as lighting and animation programming'. 'VR technology is considered to be highly useful to simulate real-life situations that are otherwise too costly or risky to experience.'* (Noh, 2019, p. 168)

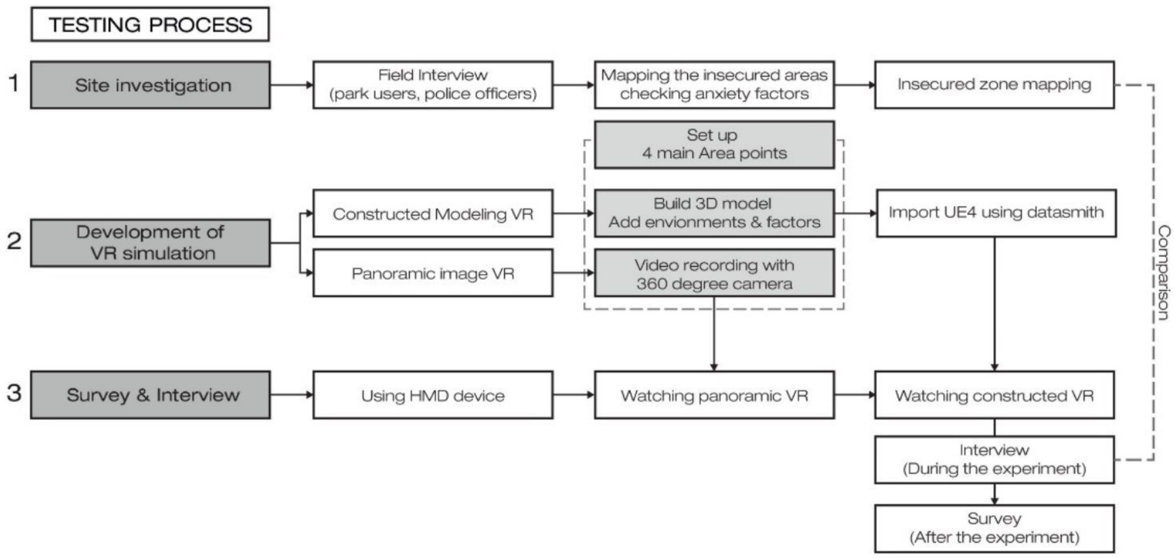

Fig. 9. Three stages of the testing process. (Source: Noh, 2019, p. 169)

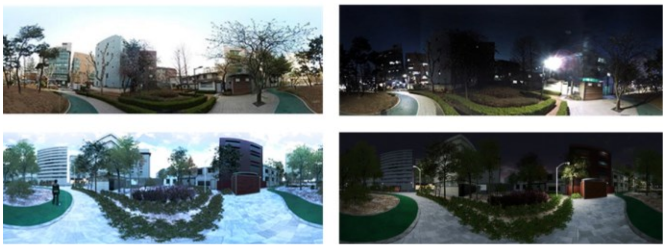

Fig. 10. Day and night scenes of image-based VR (above) and model-based VR (below). (Source: Noh, 2019, p. 170)

Fig. 11. Screen-captured insecure factors found in the studies areas. (Source: Noh, 2019, p. 172)

'(...) current CPTED approaches are criticized as the evaluation criteria merely focus on designing static elements (...) (Song, 2009). (...) In CPTED, it is important to consider dynamic environmental factors and ephemeral conditions (...), as well as static design elements.' (Noh, 2019) Land-use changes can also influence opportunities for crime. *'Indeed, the criminogenic capacity of the built form is not static–it is dynamic and ever changing.'* (Cozens, 2018, p. 73) My own comprehensive case study of a residential quarter conducted in 2012 (Benkovičová, 2015) reflected these dynamic factors and many others as well. The modification of the situations that should be taken into account, like light, shade, sound, weather, and movement, can be made easier and true danger can be avoided. This is thus useful for example at night, which is generally more dangerous and there are higher crime levels and higher crime anxiety than during the daytime (Fisher, 1992; Loewen, 1993).

One recent study has revealed that VR can *'effectively simulate a park to reveal the psychological anxiety that the elements and the environment of the park generated in park visitors. (...) Efforts have been previously made to utilize virtual reality technology and incorporate it into space design and CPTED design.'* (Noh, 2019; Fig. 9-11). In this study, a 20-minute realistic VR simulation in Unreal Engine 4 was employed for a CPTED evaluation of a high-crime city park. 30 participating students were wearing HMDs within a 3x3 m space and given questionnaires after the experiment; they were also interviewed during the experiment itself. Another study (Kavakli, 2004; mentioned in Noh, 2019) where a virtual environment was made by researchers in order to examine crime risk factors and provide an interface for training novices, which is of special interest to my own diploma thesis application design (prototype of new immersive learning experience to provide deeper understanding of CPTED concepts to enhance the traditional curriculum and the overall retention of knowledge; Fig. 12) being finalized by the end of 2022 in the study programme of Applied Computer Science at the Faculty of Informatics, Pan-European University in Bratislava, Slovakia. Moreover, a different study (Park, 2008; mentioned in Noh, 2019) suggests that simulation tools that utilize virtual reality and augmented reality technologies have the advantage that they can easily modify situations in a virtual environment while avoiding real danger or risk.

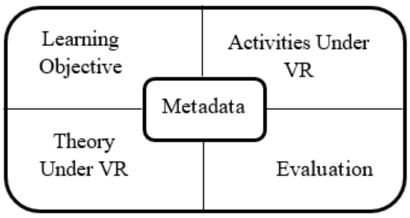

Fig. 12. Learning object model integrating VR. (Source: Munoz-Arteaga, 2020, p. 178; redrawn by Lucia Benkovičová)

SOFTWARE APPLICATION PROTOTYPE

The main goal of my own, recently developed application is studying of the information available in the created model environment to acquire knowledge from VE to be synthesised for later use in the real world. The goal is for users to learn, experience, practice, and review 12 specific tasks (listed in Fig. 13). These are especially impactful, educational, memorable, effective, and fun in VR, as has been shortly explained in the previous text. At a high level, during the app, its users will roam the scene freely to find all task windows (no matter their order) with the questions to ponder on the design of the built environment. The application category is education and training.

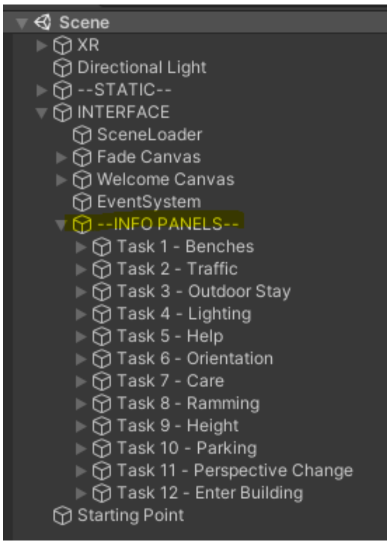

Fig. 13. Project hierarchy in Unity with highlighted task panels created in the 3D scene for VR in the given order. (Author: Lucia Benkovičová, 2022)

The following page details specification of the tasks (in Info Panels listed by names in Fig. 13) in my VR environment:

Task 1 – Benches: Are there enough benches to sit on? Are they placed well to enable natural surveillance? Can you find any security cameras? Is the street furniture in a good shape and of durable materials?

Task 2 – Traffic: Are there any sleeping policemen (speed bumps) or other elements of traffic calming to make the space safer?

Task 3 – Outdoor Stay: Attract the spaces the right amount and type of people to stay outside longer to perform desired activities? Are they easy to use by the disabled, elderly, and mothers with prams?

Task 4 – Lighting: Is the lighting of good quality along all routes, facades, and in front of all entrances? Is it constant or movement-responding?

Task 5 – Help: How easy it is to call for help? Would it be easy to get it anywhere?

Task 6 – Orientation: Is it easy to find your way in the environment and escape? Are there any visual barriers, cul-de-sacs, or potential places to hide?

Task 7 – Care: Is everything tended? Are there any other signs of physical or symbolic territoriality? How about signs of vandalism or overprotection (iron bars, high walls)?

Task 8 – Ramming: Are cars prevented from ramming or can anything absorb the collision?

Task 9 – Height: Are not any buildings too high to see what happens in the street from their inside? Does anything make buildings easier to climb?

Task 10 – Parking: Are the parking areas marked clearly and secured? How about their isolation, occlusion, and opacity of the surrounding walls?

Task 11 – Perspective Change: Once you have covered all the information panels in the scene, restart your exploration and, for a change, try to think as a villain, not a well-meaning visitor or a user!

Task 12 – Enter Building: Feel free to enter the building on the right if you like. This training, however, focuses on the exterior and there are thus no specific tasks to do inside.

Materials, data, and methods

The app, which is currently called 'VR edu CPTED' and has not been shared with anyone yet, takes place mainly in exterior of a town part with one central modern office building (with furnished interior) and a few surrounding buildings of non-specified use (originally with all textures office buildings and an apartment building) with a small network of roads (street- and bridge-level) and pedestrian spaces. This sample model's (Enscape, 2022) geometry, custom assets, and texturing have been created with Autodesk Revit (Fig. 14), BIM software helping AEC teams create high-quality buildings and infrastructure, and Enscape (a real-time rendering and VR visualization tool for BIM models) software in 2020.

Although the model itself is VR-ready (for Enscape, see Fig. 15), to be able to develop my own application in Unity, after many trials and errors (including testing different VR-development solutions), I first had to relocate the assets and textures in the Enscape plugin for Revit, then export the model using a specific workflow outlined in Fig. 16, and, finally, replace some of the textures and assets (by some more suitable from the Unity Asset Store). To be able to get at least some of the original exterior textures, I also had to export a selected 3D view of the Revit model as a DWFx file and import this file to SimLab Composer (3D software for importing models and then creating dynamic visualizations and renderings for interactive VR training sessions), where I packed the scene as an FBX file.

Upon unzipping the file, I had been provided with the textures. Then I drag-and-dropped this FBX file into Unity (without textures). After that, I extracted the materials and moved them into the Unity Materials folder. I set the material location to Use External Materials (Legacy). Once applied, the model started showing some original textures. Further, Colliders and Teleport Areas (with Fade) were added to some floor, road, sidewalk, topography, and stair objects, UI elements were created, and everything was configured and tested individually regarding functionality. Lots of other models had been explored before the final choice was made. I had been looking for a topic-specific architectural setting with more buildings at one place in VR quality with the possibility for reuse and/or publish for my educational purposes.

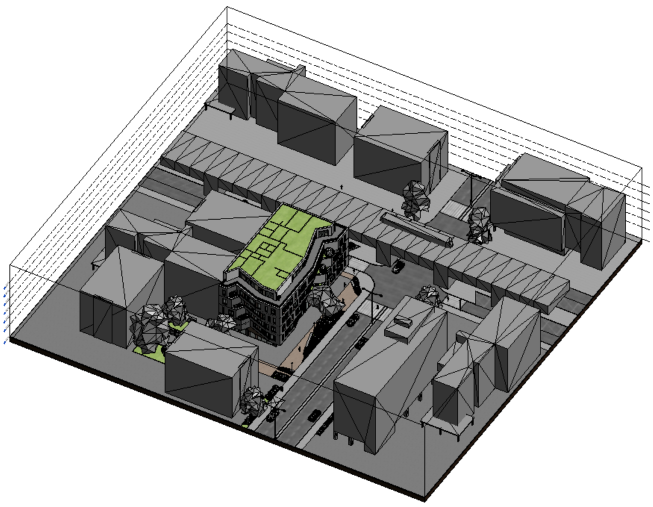

Fig. 14. A screenshot of the 3D model Starting View in Revit 2020, made by Lucia Benkovičová, 2022. (Model source: Enscape, 2022)

The application has been built in Unity 2020.3 with standard Player, Oculus XR Plug-in Management, and PC, Mac and Linux Standalone settings, targeting at 64-bit Windows OS. This experience is targeted at devices with 6 DOF giving users control over the movement and rotation. Each user needs an HMD tethered to a powerful computer. The application is optimised for use with Oculus devices. Oculus Rift is an example of a PC-powered VR (gaming) headset. It was introduced as a consumer version in 2016 and discontinued in 2021. The users should consult the current minimum system requirements required for their setup. A typical use case is intended to be an in-person English-speaking class with a teacher and necessary hardware available to use with guidance. Since there are relatively lots of users with vision defects (including myself seeing everything inside VR blurry), it needs to be added that: *'Individuals who are dependent on prescription glasses face considerable challenges when using modern stereoscopic head-mounted displays. In most instances, there is simply not enough eye relief available to accommodate the use of corrective lenses without severe discomfort or the potential for damaging the optics of both the HMD and the user's spectacles.'* (Aukstakalnis, 2017, p. 398) Those will most probably need adapters for prescription lenses, which are currently available just for some models, to experience the scenes as they really are using a VR HMD.

Fig. 15. Exterior views of the model sample made in Enscape 3.1 for Revit, opened as a standalone application. (Screenshots: Lucia Benkovičová, 2022; Model source: Enscape, 2022)

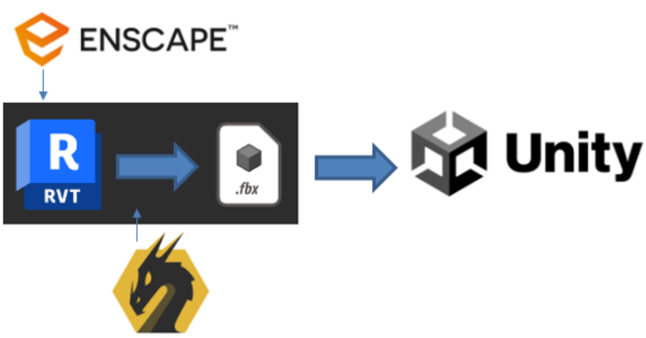

Fig. 16. Since there is currently no support for direct export from Enscape to Unity, the Revit model has been exported using the FBX Simlab export plugin for Revit, which resulted in losing all of the Enscape materials applied in the project sample. Unfortunately, no better way to export the model to Unity in order to preserve the highest quality has been found so far. (Author: Lucia Benkovičová, 2022)

Given that this app is targeting the Oculus Rift HMD, target metrics (Meta, 2022) were: 80-90 FPS, 500-1,000 draw calls (in Unity called batches) per frame, 1-2 million triangles (tris) or vertices (verts) per frame. The above-mentioned metrics have been tested using the Game Statistics and an FPS Overlay UI in the Play mode within all model parts, using the Oculus Rift HMD. As a result, some very detailed car objects have been removed to minimize polygon count. All lights are real-time. However, currently the only light source in the whole scene is a skybox from the Unity Store and all objects are marked as static for light optimisation purposes (preparation for light baking, which is generally recommended for most lights, using a minimal number of real-time or mixed lights). Light probes are not used for more realistic mixed lighting. For some actions, conditions, controls, and testing, some scripts, and prefabs from a Unity course (Unity Technologies, 2022) have been used.

Results

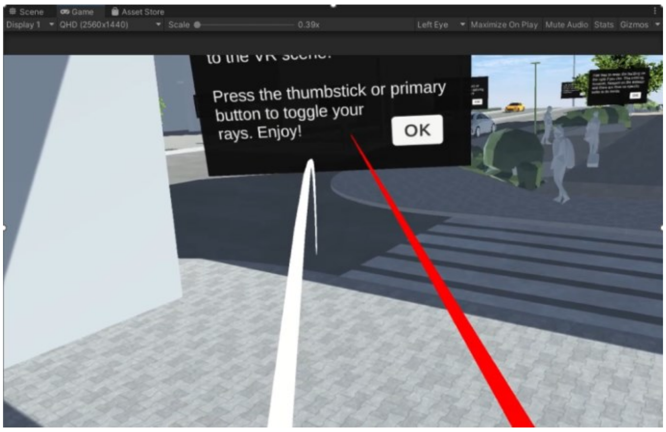

Fig. 17. A view from the Game mode in Unity with the headset on my head and both controllers in my hands (thumbs on the thumb sticks). The implemented ray interactors turn white from red when they reach something that can be interacted with. Here the left ray is ready for teleport, the red right ray is pointing at the Welcome Canvas in an area that cannot be clicked on for interaction with this object. (Author: Lucia Benkovičová, 2022)

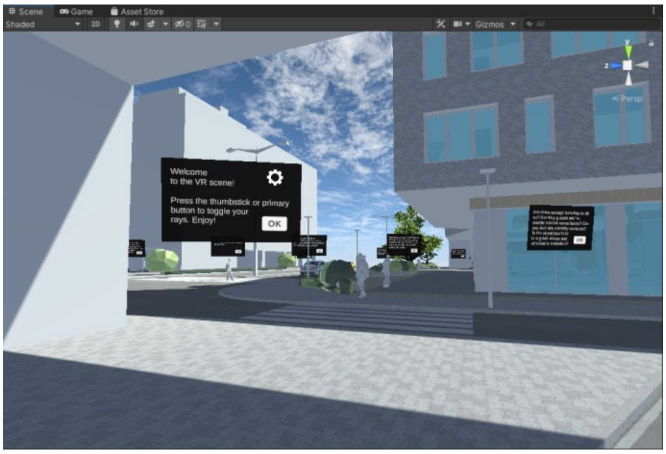

Fig. 18. A screenshot of the same model (geometry) in Unity, the chosen development environment, from the created Starting Point. (Author: Lucia Benkovičová, 2022)

The users can get around the scene with teleport as well as with continuous movement. They are not able to grab anything in the scene and there are no sockets used. However, Distance Grab is implemented but inactive since there are currently no objects to grab by hand. By default, both the left-hand and right-hand controllers have got a direct interactor. Both hands have got also ray interactors available – left one is used for teleportation, right one for interaction with the world-space user interface. The rays are activated when the Oculus Touch Controller (primary or thumb stick button) is pressed and held (Fig. 17). There is small haptic and audio feedback when the user has made a selection and also when Hover State is entered. The main menu (object Welcome Canvas) is located by the Starting Point (Fig. 18) and, from the main menu, the user gets information on the implemented controls and can access the settings menu, where they can toggle between the Snap Turn (default setting, turning set to 30°, helps prevent motion sickness - nausea) and the Continuous Movement (for wider accessibility).

Within the Welcome Canvas, there are additional UI elements for resetting the scene to its default state (object Reset Background). The user can press a secondary button (B or Y on one of the Oculus controllers) or, alternatively, press the Oculus button to access the Reset View button. To exit the app, the user either needs to press the Oculus button and then the Quit button in the Oculus UI or close the app window using the computer. To make the user experience more accessible, efficient, and comfortable, all canvases (UI elements) are set to a comfortable eye-height for reading, you can use teleport to move around, switch between snap turning and continuous movement, possibly grab things by hand from afar, fading is used on scene load and for teleportation, and some LOD (level of detail) elements, like cars or trees, have been used. The application is currently being fine-tuned with more features and awaits its first students to test and use it.

CONCLUSION

As predicted (McGreevy, 1993, pp. 194, 195), VR has greatly influenced art, architecture, computer-aided design, communications, entertainment, education, scientific visualization, simulation, training, and many other fields. *'The physical environment can be manipulated to produce behavioural effects that will reduce fear and incidence of crime.'* (eSRX, 2022) As one of the media for data visualisation in 3D (Whyte, 2002, p. 19), visualization is an alternative method of their analysis (Grantham, 1993, p. 225) that can be used for problem solving. VR comes with safe experience of distant or dangerous locations (Bricken, 1991). It enables simulations of existing environments as well as gathering data normally impossible or improbable to get (Gutiérrez, 2002; mentioned in Rangel Bernal, 2020, p. 2). *'(…) VR has immense pedagogical promise, with the potential to not only assess hypothetical environments, but also to track, shape and inform subjects' thinking towards them. In sum, VR presents considerable opportunity to gain insights into the general perception and emotional responses of proposed designs (…), reduce prototyping costs and design faults (…), evaluate different scenarios against specific criminogenic variable and identify built environment variables associated with different types of crime.'* (Cozens, 2018, p. 70) There are not many practical studies on the use of VR for this purpose, which points at a niche for more research to be conducted in this area.

On the other hand, there are many approaches to learning (Aguirre, 2020, p. 134), individual preferences and combinations used. *'Research has shown that, after two weeks, we remember 10% of what we read, 20% of what we hear and 30% of what we see. This rockets to 90% for things we do. Learning can be more effective if it is experiential, which includes strategic problem-solving skills and critical thinking, tasks that virtual reality is perfectly suited for.'* (Tustain, 2018, p. 126) Furthermore, the greatest effectiveness in learning is usually achieved with different learning styles combined, involving hearing, seeing, and doing at once (Hain, 2020). VR incorporates all of them. *'VR's deep mission (…) was to find a new type of language, or really a new dimension of communication that would transcend language as we know it.'* (Lanier, 2017, p. 87) Understanding and using VR is starting to become a basic skill for an architect and the need has emerged to further the education in this regard.

Acknowledgements

The software development part of this work has been supported by the computing resources and a PC-powered VR headset lent by the Laboratory of Virtual and Augmented Reality of the Pan-European University in Bratislava, Slovakia, which is a part of the world VR laboratory network VR First. I have also made use of a sample model whose original geometry, custom assets, and texturing have been created with Autodesk Revit and Escape software with the kind permission of the company Enscape GmbH. I would like to extend my acknowledgment to the supervisor of my last two theses on VR, Dr Ján Lacko, the current dean of the Faculty of Informatics, Pan-European University, for his invaluable lectures on VR and 3D graphics in my previous bachelor and master studies of applied computer science. I wish to thank also my previous employers in company Capturing Reality (photogrammetry software developer for creating 3D models from photographs and/or laser scans), who hired me after my doctoral studies, for having provided me with versatile opportunities and trust in my abilities, top-level knowledge, and experiences for more than four years, and enabled me to build solid foundations for my direction to focus on in my future professional development.

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