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9. VIRTUAL REALITY TECHNOLOGY IN THE CONTEXT OF SMART LIVING

9.1. Introduction

The issue of inhabitation is relatively rarely discussed in the concept of Smart Cities, considering the importance of its role in the processes of shaping cities[2]. The original concentration on aspects of maximizing the efficiency of urban infrastructures has undergone a significant transformation on two fronts, first through the implementation of digital communication technologies, then by taking into account human capital, social relationships and the potential of inclusive civic participation[3]. It should be emphasized that the pursuit of intelligent and sustainable urban development is a measure to achieve the goal of improving the quality of life of its present and future inhabitants. The quality of habitation understood as the realization of life processes is therefore the culmination of the efforts of all parties involved in the task of modeling and developing urban structures. Consideration of the transformations of inhabitation processes accompanying the emergence of a new medium in the form of virtual reality technology can bring new findings in terms of knowledge about shaping the Smart Cities of the future. Awareness of the existence and influence of virtual space on the physical world will contribute to a more conscious shaping of residential spaces, following the

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[2] Jonek-Kowalska I.: Rozwój inteligentnych miast w polsce w kontekście niezrównoważonych budżetów jednostek samorządu terytorialnego. [In:] Jonek-Kowalska I. (ed.) Wyzwania i uwarunkowania zarządzania inteligentnymi miastami. Wydawnictwo Politechniki Śląskiej, Gliwice 2019, pp. 91-106; Chrisidu-Budnik A.: Współczesne kierunki rozwoju inteligentnych miast w kontekście potencjału relacyjnego. [In:] Kusiak-Winter R., Korczak J. (red.): Ewolucja elektronicznej administracji publicznej, E-Wydawnictwo, Prawnicza i Ekonomiczna Biblioteka Cyfrowa, Wydział Prawa, Administracji i Ekonomii Uniwersytetu Wrocławskiego, Wrocław 2021, pp. 151–169.

[3] Kowalska-Styczeń A.: Badanie złożonych zjawisk społecznych w kontekście inteligentnego miasta. Inteligentny rozwój inteligentnych miast, CeDeWu Sp. z o.o., Warszawa 2020, pp. 137–146; Sim D.: Miasto życzliwe. Jak kształtować miasto z troską o wszystkich, Wysoki Zamek, Kraków 2020.

example of the late 19th and early 20th centuries, when architectural theory and practice were redefined through the awareness of the existence of physical space[4].

The research includes analyses of the influence of virtual reality technologies on the processes of habitation in the context of the formation of the phenomenon of intelligent habitation as a component of the Smart City of the future. The aim of the research is to assess the impact of modern information technologies on the processes of habitation and to formulate prospects for their future development. The starting point for the analysis is the concept of *compilation dwelling* by Grzegorz Nawrot[5] referring to the multidimensionality of inhabitation processes taking place simultaneously in the material structures of cities and in the information clouds. The complex structure of dwelling processes understood in this perspective also includes the aspect of functioning in cyberspace and the virtual world, where the city residents perform subsequent activities associated with habitation[6]. The process of relocation of activities to the virtual sphere was highlighted during the restrictions associated with the COVID-19 pandemic, which forced remote working and learning, realized through modern communication technologies. Thus, specific external conditions established a peculiar anomaly affecting the natural processes of transformation of the processes of habitation. The phenomenon of functioning in virtual space is progressing and influencing residential processes, which will be reflected in the shapes of housing spatial structures in Smart Cities of the future.

9.2. Research methods

In order to evaluate the impact of the phenomenon of virtual reality technology on inhabitation processes, I have applied the methods of historical-interpretive research and logical argumentation[7]. I considered the common factor of the analyzed phenomenon of virtual reality and processes of inhabitation to be the spatial context proper to the issue of architecture. Hence, the first stage of analysis focuses on the sensory perception of space, which in virtual conditions becomes an object of implementation of subsequent

[4] Leśniakowska M.: Przestrzeń w architekturze, [Online] 2012, https://teoriaarchitektury.blogspot.com/2012/07/marta-lesniakowska-przestrzen-w.html.
[5] Nawrot G.: O współczesnych formach zamieszkiwania w mieście, Wydawnictwo Politechniki Śląskiej, Gliwice 2015; Nawrot G.: Symultaniczność i kompilacja a obraz miejsca, Budownictwo i Architektura, 2018, Vol. 18, No. 2, pp. 29–38.
[6] Nawrot G.: O współczesnych formach zamieszkiwania w mieście, Wydawnictwo Politechniki Śląskiej, Gliwice 2015.
[7] Niezabitowska E.: Metody i techniki badawcze w architekturze, Wydawnictwo Politechniki Śląskiej, Gliwice 2014.

inventions aiming at simulation of the fullest possible sensual experience. The work is summarized with an overview of existing tools for virtual space exploration. Thereafter, I proceed with an interpretation of past applications of virtual reality technology in other industries and disciplines concluding with a prediction for further collaborative development of inhabitation processes and virtual reality technology in the Smart City of the future.

9.3. Virtual reality (vr) technology

9.3.1. From simulation to alternative reality

The phenomenon of virtual reality does not have a homogenous origin, but it is the effect of collective and simultaneous actions of creators of various industries, therefore the beginnings of the technology can be found in many sources. There are three essential elements for its existence: Immersion, Interaction, and Imagination (3xI)[8].

To achieve 3xI, it is necessary to recreate the sensory experience that drove inventions related to the film industry in the 20th century. Understanding the complexity of the sensory experience of space, Morton Heilig constructed devices in the 1950s and 1960s that form the basis of today's equipment in the category of creating immersive experiences. These were, represented in Figure 9.1, the 1960 *Stereoscopic-television apparatus for individual use* - the prototype of VR goggles and created two years later *Sensorama simulator*[9].

The stereoscopic-television apparatus was equipped with kinescopes, lenses, headphones, and blowers that emitted wind and smells, while the Sensorama was already using a three-dimensional image in a wide field of view, stereo sound, generated wind, smells, and vibrations.

[8] Burdea G. C., Coiffet P.: Virtual reality technology, John Wiley&Sons, Hoboken, New Jersey 2003.
[9] Burdea G. C., Coiffet P.: Virtual reality technology, John Wiley&Sons, Hoboken, New Jersey 2003.

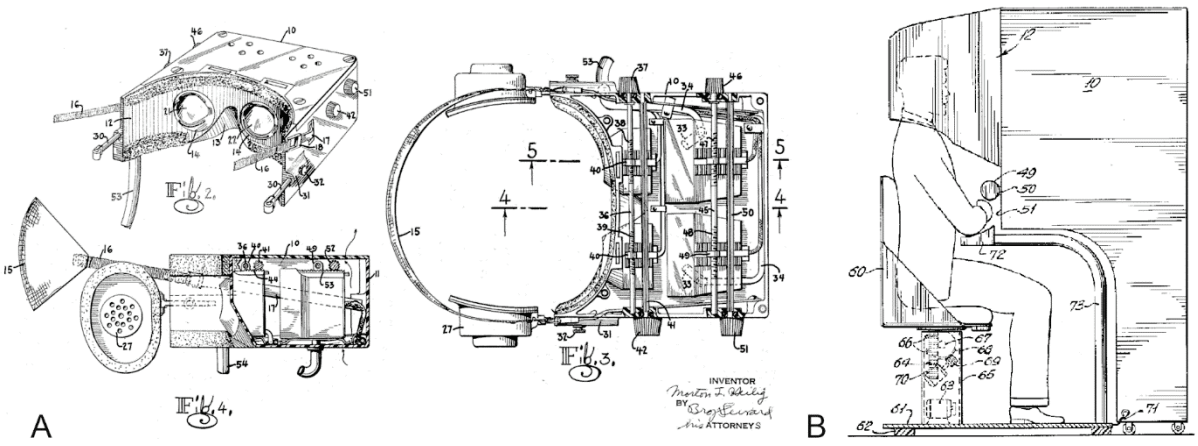

Fig. 9.1. A: Morton Heilig patent – Stereoscopic-television apparatus for individual use, B: Morton Heilig patent – Sensorama simulator device.

Rys. 9.1. A: Patent Mortona Heiliga – Stereoskopowo-telewizyjny aparat dla indywidualnego użytkownika, B: Patent Mortona Heiliga – symulator Sensorama.

Source: Ad. A.: Figures 3,4 and 5 of U.S. Patent 2,955,156, Morton Heilig, Public domain, via Wikimedia Commons; Ad. B.: Figure 5 of U.S. Patent 3,050,870, Morton Heilig, Public domain, via Wikimedia Commons[10].

Another source of VR technology can be considered the artistic and technological activities of Myron W. Krueger, who developed a series of installations aimed at creating a simulation of a parallel environment that allows participants to interact mutually. Subsequent installations: 1969's *Glowflow*, 1970's *Metaplay*, 1971's *Psychic Space*, and 1975's *Maze* and *Videoplace* were ventures aimed at creating a responsive environment[11]. These explorations continued with the later 1992 realization of CAVE (Cave Automatic Virtual Environment) by Thomas DeFanti and Daniel Sandin[12]. The concept of a *virtual cave*, which is a separate, real space serving the purpose of exploitation of the virtual environment, to this day provides an ideological and technical basis for the implementation of new technological solutions, which indicates that both worlds, real and virtual, have common elements and remain dependent on each other.

Figure 9.2 shows the fundamental change between virtual cave technology and VR goggle technology - in the first case, the physical space, in which the observer is located, is at the same time the limit for his or her mobility, and in the second case, by using goggles and omnidirectional treadmills, the physical space no longer limits the observer, who can explore the unlimited virtual space in an atavistic way.

[10] U.S., New York Patent nr 2,955,156, 1960; U.S., New York Patent nr 3,050,870, 1962.

[11] Krueger M.: Responsive environments. New York, NY, USA: Association for Computing Machinery, 1977, [In:] AFIPS '77: Proceedings of the June 13-16, national computer conference, 1977, pp. 423–433.

[12] Asanowicz A.: Systemy rzeczywistości wirtualnej w architekturze, Architecturae et Artibus, 2012, pp. 5–12.

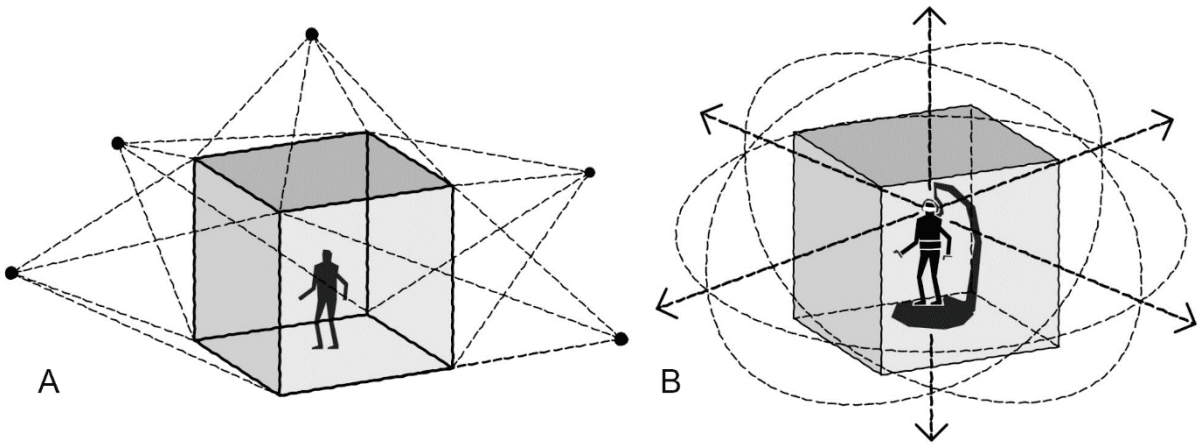

Fig. 9.2. Evolution of virtual reality technology – types of projection: A – model "CAVE" (Cave Automatic Virtual Environment); B – model model using VR goggles and an omnidirectional treadmill

Rys. 9.2. Ewolucja technologii wirtualnej rzeczywistości – typy projekcji: A – model „CAVE" (Cave Automatic Virtual Environment); B – model wykorzystujący gogle VR oraz bieżnię wielokierunkową

Source: Author's scheme, 2022.

Simultaneously, the creation of an alternative three-dimensional space was addressed by the IT industry, which soon after the transfer of two-dimensional drawing mechanisms to computer screens has created a virtual three-dimensional environment supporting design processes, which gave rise to 3D modeling[13]. Since then, virtual reality technologies have been continuously developed and applied in further fields: medicine, entertainment, design, training, scientific and artistic industries (Figure 9.3). For the purposes of architecture and construction, design software is a particularly important application of three-dimensional digital technologies, including BIM[14], parametric design software[15] as well as three-dimensional digital surveys that truly shape the image of contemporary architecture. The following step involves the creation of virtual representations of existing objects in the form of digital twins[16] enabling not only the presentation of concepts, investment planning and conducting multi-discipline and social consultations, but also simulations, collection of data from intelligent devices in buildings and cities, allowing

[13] Śliwa A.: IT technologies in architecture and space representation. Bruno Zevi methods revisted, Architecture Civil Engineering Environment, 2019, Vol. 12, No. 3, pp. 35–40.

[14] Building Information Modeling.

[15] Januszkiewicz K.: Projektowanie parametryczne oraz parametryczne narzędzia cyfrowe w projektowaniu architektonicznym (Parametric design and parametric digital tools in architectural design), Architecturae et Artibus, 2016, Vol. 3, pp. 43–60.

[16] Bujari A., Calvio A., Foschini L., Sabbioni A., Corradi A.: IPPODAMO: a digital twin support for smart cities facility management, Rome: 2021. [In:] GoodIT '21: Conference on Information Technology for Social Good, pp. 49–54.

for simulations, prediction of problems, identification of design flaws, and verification of potential solutions. A significant change comes with new instruments in the long-standing design paradigm in all design disciplines, including architecture[17]. The next step in the development of digital technologies is to create not a simulation, but an independent, alternative environment with its own development prospects, whose unlimited possibilities we are not yet fully aware of[18]. The embodiment of the idea of alternative, virtual reality is becoming a rising popular term metaverse – the internet considered as an imaginary area without limits where you can meet people in virtual reality[19].

Fig. 9.3. Applications of virtual reality technology
Rys. 9.3. Zastosowania technologii wirtualnej rzeczywistości
Source: Author's scheme, 2022.

9.3.2. Sensory experience simulators

Virtual reality technology represents the next step in the work of improving the representation of space[20]. Conventional methods of representing three-dimensional reality were attempts to translate multisensory experience into the symbolic language of signs (technical projections and cross-sections), flattened it to a two-dimensional form (elevation views, perspectives) or were unable to satisfy the parameter of scale (mock-ups)[21]. The three-dimensional real world, together with the mechanisms regulating its cognition remained out of reach. Digital technologies have

[17] Słyk J.: Space and form of information architecture, Przestrzeń i Forma, 2019, Vol. 40, pp. 9–24; Helenowska-Peschke M.: Architektura w kontekście fenomenu wirtualnej rzeczywistości, Czasopismo Techniczne, 2011, Vol. 14, pp. 141–146.
[18] Grosz E.: Architecture from the outside: Essays on Virtual and Real Space, The MIT Press Cambridge, Massachusetts, London 2001.
[19] Metaverse [Online], https://dictionary.cambridge.org/dictionary/english/metaverse.
[20] Zevi B.: Architecture as Space. How to Look at Architecture, Horizon Press, New York 1957; Śliwa A.: IT technologies in architecture and space representation. Bruno Zevi methods revisted, Architecture Civil Engineering Environment, 2019, Vol. 12, No. 3, pp. 35–40.
[21] Zevi B.: Architecture as Space. How to Look at Architecture, Horizon Press, New York 1957; Śliwa A.: IT technologies in architecture and space representation. Bruno Zevi methods revisited, Architecture Civil Engineering Environment, 2019, Vol. 12, No. 3, pp. 35–40.

made it possible to omit the difficulties associated with the actual creation of space, reducing it to the necessary minimum in the form of CAVE, three-dimensional reality has been created in a digital environment, thus reducing the former problem to the challenge of satisfying the needs of the human senses, through which we experience space and the objects in it. The digital aspect of this method has one fundamental property that has not been available before – it enables remote sharing of the created spatial reality in any place and at any time.

Table 9.1

Tools for sensory exploration of a virtual space

No.	Tools for sensory exploration of a virtual space	
	Sense	**Device**
1	sight	screens, monitors, projectors, virtual glasses (VR goggles)[22]
2	hearing	speakers, headphones
3	touch	vibrating vests and belts, software simulated force resistance, blowers, the virtual hand metaphor, controllers with vibrotactile motors, mechanical actuators enabling users to feel the shape of virtual objects, 'plasters' using SMA technology, a full-body haptic suit deploying electrical muscle stimulation[23]
4	smell	masks and air blowers imitating scents, scent printers, scent diffusers, scent screens[24]
5	taste	taste simulators based on electric charge and heat emission[25]
6	balance	VR multi-directional treadmills[26], balance platforms[27]
7	temperature	temperature-emitting clothing[28], trigeminal based temperature illusions[29]

Based on the author's research.

The experience is multidimensional, and its individual elements generate information about the perceived structures – the integration of all sensations leads to the creation of a complete image of the created reality[30].

[22] There are a number of models available in the commercial video game market: Oculus Rift, Oculus Go, HTC Vive, Samsung Gear, Play Station VR.

[23] Price S., Jewitt C., Yiannoutsou N.: Conceptualising touch in VR. Virtual Reality, 05 January 2021, pp. 863–877.

[24] Gosain D., Sajwan M.: Aroma tells a thousand pictures: digital scent technology a new chapter in it industry, International Journal of Current Engineering and Technology, 25 August 2014, pp. 2804–2812.

[25] Kerruish E.: Arranging sensations: smell and taste in augmented and virtual reality, The Senses and Society, January 2019, pp. 31–45.

[26] Similar to VR goggles, for video game purposes, there are available omnidirectional treadmills: Virtuix Omni, KatVR, KatWalk MINI.

[27] For a variety of entertainment and health applications, there are balance-based devices such as platforms: Icarus or The Prokin 212 MF system.

[28] Markiewicz J., Niedzielski P.: Rozwój symulatorów w technologii VR jako przykład oszczędnych innowacji, Optimum. Economic Studies, 2021, pp. 44–57.

[29] Brooks J., Nagels S., Lopes P.: Trigeminal-based temperature illusions. [In:] CHI '20: CHI Conference on Human Factors in Computing Systems, Honolulu, HI, USA 2020, pp. 1–12.

As presented in Table 9.1, we can observe a significant progress in the development of devices and technologies that enable digital transmission of information addressed to the senses: sight, hearing, touch, smell, taste, balance or temperature[31]. VR technology is finding more and more applications in the gaming, education and training industries[32]. Simulators are constructed to imitate specific circumstances, focusing on the feelings of those participating in the simulations[33]. It seems to be only a matter of time before the full experience of three-dimensional reality offering the full spectrum of stimuli will be fully reflected. A completely immersive exploration of virtual reality created in a digital environment may contribute to opening a new chapter in the history of civilization.

9.4. Smart dwelling as a component of the smart city

The adjective *smart* is most often used to describe technology, cities and homes, but less often in the context of living as a process[34]. The IT-based equipment of apartments introduces a number of improvements, but the real transformations in this field concern changes in daily functioning. Relocation of activities connected with habitation to the sphere of virtual reality may influence the shape of houses in a practical way, just as the evolution of the house – *edifice* – corresponds to cultural and civilization transformations[35]. The transfer of habitation processes to immersive and responsive virtual spaces may redefine the concept of *smart habitation* in the future.

9.4.1. Applications of virtual reality technology in habitation processes

The processes of habitation are constantly transforming, shaping the image of residential architecture as their physical emanation. The processes of habitation, on the other hand, depend on the daily activities that take place inside or outside the home – in

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[30] Pallasmaa J.: Oczy skóry, Instytut Architektury, Kraków 2012.
[31] Cognitive science specialists distinguish other senses besides the basic five (Pallasmaa, 2012).
[32] Markiewicz J. i Niedzielski P.: Rozwój symulatorów w technologii VR jako przykład oszczędnych innowacji, Optimum. Economic Studies, 2021, pp. 44–57.
[33] Markiewicz J. i Niedzielski P.: Rozwój symulatorów w technologii VR jako przykład oszczędnych innowacji, Optimum. Economic Studies, 2021, pp. 44–57.
[34] Chrisidu-Budnik A.: Współczesne kierunki rozwoju inteligentnych miast w kontekście potencjału relacyjnego. [In:] Kusiak-Winter R., Korczak, J. (red.): Ewolucja elektronicznej administracji publicznej, E-Wydawnictwo, Prawnicza i Ekonomiczna Biblioteka Cyfrowa, Wydział Prawa, Administracji i Ekonomii Uniwersytetu Wrocławskiego, Wrocław 2021, pp. 151–169.
[35] Nawrot G.: Symultaniczność i kompilacja a obraz miejsca, Budownictwo i Architektura, 2018, Vol. 18, No. 2, pp. 29–38.

workplaces, schools or restaurants. The range of activities that take place in dwelling places depends on many factors, among others: economic status, cultural aspects, or technological advancement. The development of IT technologies has made it possible to carry out some of these activities in cyberspace, as it was observed during the restrictions in functioning related to the COVID-19 pandemic. Activities involving interpersonal contact and information transfer can be carried out remotely. Among the activities that define the state of living, we can distinguish two groups: the first group includes activities that focus on body needs – shelter, sleep, preparing and eating meals, taking care of personal hygiene, and the second group that includes activities that often focus on social interactions such as work, study, recreation, and social meetings. By now the second group of activities can be performed to a significant extent in the cyberspace[36] (Figure 9.4). As Piotr Cichocki claims: "The context of digital virtual architectures is a new phenomenon, dynamically entering the world of human relations (...)"[37], thus, remote communication redefines the ways of fulfilling the needs of human relationships, changing the requirements for the physical spaces that serve them, which also applies to residential spaces.

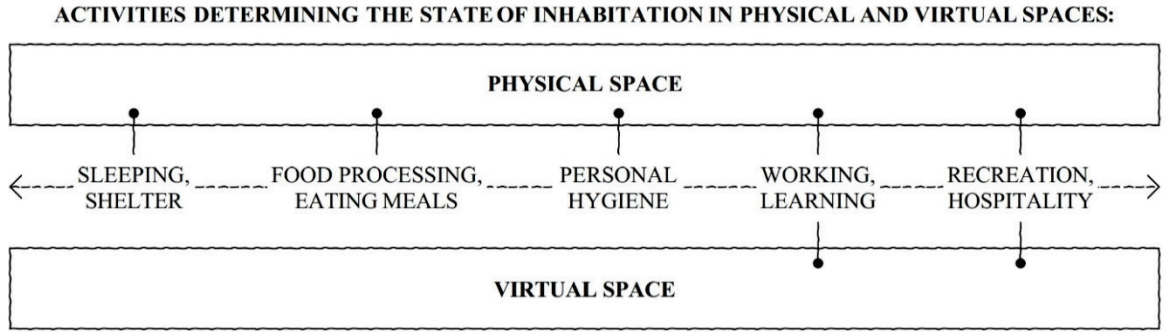

Fig. 9.4. Activities determining the state of inhabitation in real and virtual spaces,
Rys. 9.4. Czynności określające stan zamieszkiwania w przestrzeniach fizycznej oraz wirtualnej
Source: Author's scheme, 2022. Based on: (Nawrot, O współczesnych formach zamieszkiwania w mieście, 2015, str. 141)

So far, the implementation of virtual reality technology for training purposes shows the advantages of these solutions in the areas that, in many aspects, can also relate to residential housing. On the basis of the research results38, it can be assumed that extending the non-transformable physical space of dwellings with virtual space for

[36] Not every type of work is possible to carry out remotely.
[37] Cichocki P.: Projektowanie relacji. Czyli o tym jak architektura internetu i jej twórcy wytwarzają społeczne praktyki, [In:] Świątkowska B. (ed.) My i oni. Przestrzenie wspólne / Projektowanie dla wspólnoty. Fundacja Bęc Zmiana, Warszawa 2014, pp. 192–203, str. 193.
[38] Markiewicz J., Niedzielski P.: Rozwój symulatorów w technologii VR jako przykład oszczędnych innowacji, Optimum. Economic Studies, 2021, pp. 44–57.

entertainment, sports, socializing, work, and study can contribute to reducing the consumption of physical spatial resources and environmental impacts associated with the construction industry and transportation.

9.4.2. Spatial consequences of the presence of virtual reality technology in residential structures

Changes in the patterns of everyday activities are reflected in the structure of dwellings (Table 9.2). Modern dwellings consist of adequately equipped rooms dedicated to specific activities: from sleeping, through resting, preparing and eating meals, personal hygiene, work, study and various entertainment, to entertaining guests. Some of these spaces are merged or multifunctional due to the limited space of the apartments. Activities that require most privacy or are intended for activities that require isolation and concentration remain separate. The emergence of a new type of activity in the form of virtual space exploration will create the need to separate and equip another room or rooms depending on the number of residents and their needs in terms of virtual reality use. Just as the appearance of computers has revolutionized the design methods of office workstations, the hardware requirements associated with the exploration of virtual space will likely change the physical space structures of housing, work and study spaces. The existing solutions and devices for virtual space exploration indicate that the spatial needs of the new activity can be met by providing a separate room – a virtual cave – allowing for free movements, or large enough to accommodate the largest piece of equipment, that is a multi-directional treadmill, a specialized chair, or a balance platform. Due to the need to ensure immersion, the room may be additionally soundproofed, but it does not require a window or natural sunlight. The multifunctionality of VR equipment provides the ability to perform a variety of activities, so a dedicated room can function as a place for work, study, recreation without the need to expand the space dedicated to it. If in the future there will be a general change in the forms of activity due to the further development of virtual reality technology, perhaps the VR function will replace the current functions of the existing supplementary rooms, such as playrooms, game rooms, studios, or study rooms.

Table 9.2

Premises for activities determining the state of inhabitation

No.	Premises for activities determining the state of inhabitation		
	Activity group	**Facility**	
1	sleeping, shelter	bedrooms, living rooms	
2	food processing, eating meals	kitchens, dining rooms	
3	personal hygiene	toilets, bathrooms	
4	working, learning	workshops, offices, children's rooms, study rooms	virtual caves
5	recreation, hospitality	playrooms, game rooms, gyms, guest rooms, lounges	

Based on the author's research.

9.5. Conclusions and summary

Dwelling understood as a process is relatively rarely a subject of discussions related to the idea of Smart Cities. Nevertheless, significant transformations related to the development of modern digital technologies are taking place in this area. The changes do not only concern the use of more and more advanced equipment and the central and remote control of apartments, but above all they concern changes in the everyday functioning of residents, thus affecting the essence of habitation, which is reflected in residential architecture.

The development of virtual reality technology corresponds to the successive attempts to satisfy the needs of the human senses as comprehensively as possible. The aim of subsequent devices is to create real or simulated stimuli to reproduce an immersive and responsive experience of created space and the objects in it. Virtual reality technology is finding an increasingly wide field of implementation. Research indicates that the field of habitation may provide a promising ground for the implementation of virtual reality technology, which is already applied in the realization of various daily activities, touching the spheres of entertainment, socializing, study, and work. Changes in the ways in which everyday activities are carried out will force changes in the shape of dwellings through the need for separate rooms dedicated to VR needs.

Assuming that the current progression of the development of digital technologies and simulation devices will be maintained, we can suppose that in the near future functioning in a multidimensional virtual reality will be highly immersive and even difficult to

distinguish from physical reality. Under such conditions, inhabitation will probably be fully compilational and multidimensional, but it is difficult to judge today how this will affect the quality of inhabitation due to the excessive number of unknowns.