Review


Xingxing Jia, Jingcheng Xu, Yucheng Xu, Hongyi Li, Siqi Peng and Bing Zhao *

College of Landscape Architecture, Nanjing Forestry University, Nanjing 210037, China; jiaxingxing@njfu.edu.cn (X.J.)
* Correspondence: zhbnl0118@njfu.edu.cn; Tel.: +86-13605167303

Abstract: Numerous studies have confirmed the positive impacts of real forests in areas such as stress relief. However, not everyone can visit forests easily. Virtual technologies offer new ways of experiencing forests for people who are hindered by real-life conditions and provide researchers with a manageable mode of study. Recently, there has been an influx of relevant research; however, themes within the overall perspective of the field remain unclear. This study aimed to review the literature and provide an overview of the potential health benefits of virtual forests. Research themes were extracted, and a conceptual framework for the multidimensional effects of virtual forest exposure was proposed from a holistic perspective. We analyzed studies using descriptive analytical methods through the Scopus, Web of Science, and PubMed databases and snowball searches. In total, 58 studies were included. This review identified four themes and segments throughout the virtual forest exposure process: core elements, experiences, effects, and circulation. We propose a new conceptual framework for a holistic perspective that incorporates technological features that are specific to virtual environments and makes connections to real forests. Finally, perspectives for future research in virtual forest therapy and its practical implications are discussed.

Keywords: virtual technology; virtual reality; virtual forest; forest therapy; forest exposure; multidimensional effects

1. Introduction

With accelerating urbanization, physical and mental health problems are becoming increasingly prominent in the population. According to the United Nations, approximately 55 percent of the world’s population lives in urban environments, and this figure is expected to increase to 68 percent by 2050 [1]. Technostress has led to several unhealthy behaviors owing to changes in the way that modern people live and work and the increasing prevalence of electronic devices [2]. The public’s access to nature has gradually decreased, and nature-deficit disorder and the extinction of experience have become common phenomena in today’s society [3–5]. The public are expected to gradually pay more attention to natural experiences, with a gradually increasing demand for them.

The use of nature to address public health issues has become a cutting-edge topic [6]. Forest therapy is one of the most popular forms of healthcare worldwide. Forests are one of the most pristine, highly encapsulated, and immersed forms of nature, and are the largest natural ecosystems among terrestrial ecosystems, providing a wealth of ecosystem services (ESs) to humans, which are particularly important in maintaining their health and well-being; forests have been recognized as “a great health machine” [7]. Furthermore, studies have demonstrated that forest-based natural environment intervention programs are more effective in promoting individual well-being than gardens or urban parks [8]. Public health authorities are beginning to progressively use exposure to the natural
enviroment as an upstream health promotion intervention [9]. Forest bathing has been studied as an alternative therapy to improve physical and mental health and has received greater attention during the COVID-19 pandemic. Several countries and organizations have proposed relevant plans [10,11] and integrated them into their healthcare systems. Corresponding international organizations have also been established, such as the International Society of Nature and Forest Medicine (INFOM) [12] and the International Nature and Forest Therapy Alliance (INFTA) [13]. The “integration of forest therapies into public health” has become an important issue [14]. A few countries have integrated forest therapies into their healthcare system to reduce pressure on it; examples include the green prescription program in New Zealand, nature prescription programs in the United States [15], and the evidence-based nature prescription program (PaRx) in Canada [16].

Regardless of the numerous health benefits that are offered by real forests, access is limited by various factors, such as obstructed travel conditions for certain populations (e.g., people with disabilities, submarine workers, Arctic scientists, and astronauts) and the time cost for the working population [17]. The World Health Organization estimates that 15% of the world’s population has some form of mobility impairment. Various blockades and controls caused by pandemics may also limit the use of nature as a non-pharmacological intervention for stress relief. Moreover, potential safety issues associated with real forests, such as wild animals (e.g., spiders and snakes) may pose a threat [18]. Darkness, solitude, and hanging or falling branches in forests may cause psychological fear [19]. Several infectious diseases are associated with forests, such as the Puumala virus (PUUV) and malaria, and forests can potentially expose people to disasters such as fires and floods [20]. Certain scholars have developed the Anti-Environmental Forest Experience Scale (AEFES) [21] to address the potential negative effects of real forests. Therefore, seeking complementary programs for exposing the public to nature to effectively improve physical and mental health has become an urgent issue.

With technologies and concepts represented by virtual reality (VR) and meta-uni-verses becoming popular, virtual forest environments have emerged as a potential solution [22]. Virtual technology is increasingly being used in the healthcare field. Numerous scholars have predicted the myriad application prospects of virtual technology in psychotherapy [23–25]. The concept of “Technobiophilia”, as an expansion and extension of Wilson’s 1984 “pro-biotic hypothesis”, emphasizes the connection between the digital world and nature. Technobiophilia is “the innate tendency to focus on life and vital processes as they appear in technology” [26], which simply means that humans will use technology to bring nature into their lives, such as setting up a mobile phone or computer screen as a virtual natural landscape. This concept can potentially become an important guiding principle for global environmental protection and urban development [27]. According to Schneider’s four-stage theory, forest therapy research is currently in the third stage of scientific research process. More research on using new technologies and decision making frameworks to solve practical problems, such as wearables and immersive virtual environment technologies, will be conducted at this stage [28]. In terms of practical applications, to balance the contradiction between the growing need to experience nature and its various constraints, forest experiences using VR technologies have become a valuable compromise and complementary solution [29].

The potential of virtual technology in nature and health research has been expressed in several studies. An early paper categorized the types of human–nature interactions into indirect, incidental, and intentional interactions, with virtual exposure falling into the indirect interaction category [30]. Pursuing a research agenda on nature and health, a multidisciplinary group listed Technological Nature (Domain 5: Technological Nature) as one of seven research areas and proposed five research priorities [6]. Another study analyzed the potential needs, opportunities, and challenges of digital forest recreation in the metadata era [31]. Bibliometric mapping analysis also revealed “VR” as an important cluster in forest therapy research and a relatively new research topic [28].
We classified forest exposure into three categories: actual, potential, and virtual. Actual exposure may involve modes such as outdoor sports, social activities, and five-sense experiences [32–34]; potential exposure may involve the climate regulation effect of forests and air purification [35,36]; however, the role of virtual forest exposure in the overall scheme of forest exposure and its effect on human health is unclear (Figure 1). With an increase in the number of virtual nature studies, an increasing number of reviews and meta-analyses have supported the existence of a link between virtual nature exposure and health [37,38]. However, no study has elucidated and reviewed the health benefits of virtual forests from a holistic and process-wide perspective. First, although several reviews have addressed real forest experiences [39], the number of reviews on virtual forests as a new research area remains relatively small. Second, a few previous reviews have included both real and virtual forests, considering them together for discussion [40]; however, regardless of real and virtual forests sharing certain elements, virtual is nevertheless a replica of the real, whereby a certain amount of information loss is inevitable in the process of replication, and the two may have different potential mechanisms of action in terms of health benefits. Additionally, existing reviews frequently combine various types of natural environments and discuss them. A few reviews have frequently used the term NATURE, thus considerably broadening the scope of research, including forests, water bodies, deserts, parks, beaches, underwater, spaces, and several other types of nature [38]. Owing to the diversity of types of nature, certain studies may not be comparable.

In the rapidly evolving landscape of technology and environmental studies, there is a compelling need to synthesize scattered information and delve into the diverse aspects of the effects of virtual forests. This review can assist us in constructing a complete framework for forest exposure. Beyond the academic realm, understanding their multidimensional effects becomes pivotal for informed decision making, whether in conservation efforts, urban planning, or environmental education. Additionally, as virtual environments are integrated into healthcare and therapeutic practices, our review can introduce
policymakers, healthcare professionals, and practitioners to the potential applications of virtual forests in health promotion.

We conducted a comprehensive narrative review in this study to understand more deeply the overall state of research on the health benefits of VR forests. Another form of synthesis, as opposed to a narrative review, is a systematic review. Narrative reviews are syntheses of qualitative studies that describe the results of other studies and provide explanations and critiques without focusing primarily on the statistical significance of the findings [41–43]. Most current review studies focus only on a part of the entire process of virtual nature exposure, for example, a certain health outcome, such as stress and emotional arousal [44], psychological well-being [45], and nature connection [38]. However, we believe that focusing on the entire process and not on specific details is more appropriate for synthesizing knowledge in this emerging field. Because of the novelty of virtual technology research and the multidisciplinary nature involved, a narrative synthesis may be more appropriate for this study. To the best of our knowledge, no reviews are available on the entire process of virtual forest exposure, nor is there a complete conceptual framework that addresses the health benefits of virtual forests. Although a few conceptual frameworks have been proposed for real forest therapies [32,46], they are not fully applicable to virtual forests, especially because, unlike physical forests, virtual forest exposures are based on virtual technology, and therefore, technological features require particular attention. In addition, the overall features of virtual forests should consider the negative effects in addition to their benefits. Ultimately, we focused on the natural type of “forest” and the holistic process of virtual forest exposure, using a narrative approach to identify and summarize the literature.

This study first aimed to review the existing literature on the potential effects of virtual forests. Second, we intended to develop a conceptual framework from a complete-process perspective. The third and final goal was to discuss the strengths and limitations of virtual forest environments in practice and research and provide an outlook for future research.

2. Materials and Methods

We developed keywords for our search by referring to the search strategies of previous review studies [37,40,47,48], dividing the searched topics into three categories, “virtual”, “forest”, and “health”, and excluding terms from unrelated disciplines. The search protocols are shown in the Supplementary Materials (Table S1).

We then performed keyword searches using the following three databases: Scopus, PubMed, and Web of Science. All studies published before September 2023 were retrieved. In addition, other publications cited in the anthology were reviewed using snowballing methodology and added to relevant research.

The inclusion and exclusion criteria were as follows: (1) Types of literature: Certain types of articles were excluded, including comments, letters, editorials, viewpoints, correspondence, gray literature, and articles without a full text. (2) Language: Non-English articles were excluded. (3) Field of study: Articles published in journals in unrelated fields, such as mathematics, chemistry, materials science, and meteorology, were excluded. (4) Exposure mode: Studies based only on real forest environments were excluded. (5) Nature type: Studies wherein the dominant landscape discussed was desert, grassland, beach, underwater, garden, vertical greening, indoors, or built environment, etc., were excluded. Exposed landscape types that included forest ecosystems or forest tree species as the dominant landscape type were considered. (6) Type of study: Only interventional studies based on laboratory tests were included, and observational studies were excluded. (7) Components of forests: Research on forest environments situated in areas such as city parks, nature parks, forest parks, nature reserves, etc., was selected. The composition of the forest environments included not only types of trees, but also types of forests accompanied by trails, blue spaces (rivers, lakes, creeks, etc.), structures (cabins, bridges, etc.),
wildlife (songbirds, small mammals, bees, etc.), and natural sounds (bird calls, wind sounds). After all iterations, 58 studies were selected for this review.

3. Conceptual Framework

This study presents a conceptual framework for the multidimensional effects of virtual forests. A comprehensive review of the existing research on the effects of virtual forests was conducted to identify the influencing factors and mechanisms and refine the key themes. With reference to, but different from the conceptual frameworks proposed by real forest therapy, naturopathy, and nature exposure [46,49], we constructed a conceptual framework of the entire process from the perspective of “core element-experience-effects-circulation” for virtual forests (Figure 2). The three core elements of virtual forest exposure are the forest (forest type, storytelling, etc.), technology (device, medium, technical characteristics), and participants (sociodemographic, natural experience, VR experience, etc.). The experiential processes include sensory stimulation, interaction, and dosage. The effects include individual-oriented (physiological, emotional, and cognitive), connection-oriented (social, ecological, and transcendental), and negative (motion sickness). Circulation then includes the intention to revisit the virtual or real forest. There are interdependencies among these four categories. The design and selection of core elements directly impact user experiences, which, in turn, influence the effects. Simultaneously, the positivity and sustainability of the effects reciprocally affect user engagement and the circulation process. Thus, these four categories form an interconnected cyclic system, working together to facilitate the realization and ongoing development of health benefits in the virtual forest. The framework not only reflects the entire process of revealing the multidimensional effects of a virtual forest from a holistic perspective but also establishes a connection with the real forest, constituting a virtuous circle. The specific elaboration of the framework and the supporting research is shown in the Section 4.
4. Results

4.1. Study Characteristics

In total, 58 studies were included in this review; detailed information is provided in the Supplementary Materials (Table S2). Twelve studies were published in 2023 (as of September), thirteen in 2022, eleven in 2021, thirteen in 2020, and ten before 2019, suggesting a gradual increase in the popularity of the topic. These studies were conducted across Asia, Europe, North America, and Australia. Specifically, 24 studies were conducted in Asia (10 in China, 5 in the Taiwan region, 2 in Singapore, 2 in Malaysia, 2 in Turkey, 1 in South Korea, 1 in Japan, and 1 in Thailand), 17 in Europe (5 in Germany, 3 in Italy, 3 in Sweden, 2 in the UK, 1 in Norway, 1 in Finland, 1 in France, 1 in Ireland, and 1 in the Czech Republic), 13 in North America (10 in the United States and 3 in Canada), and 4 in Australia.

4.2. Core Elements of Exposure

The core elements of virtual forest exposure were classified into three categories: technology (device, medium, technical characteristics), forest (forest type, forest density, biodiversity, etc.), and participants (sociodemographic, natural experience, VR experience, etc.). The relationship between the three elements can be explained as follows: the
virtual forest landscape is digitally processed and then exposed to participants through the virtual medium.

4.2.1. Technology

Devices (display systems) include a desktop display (2D), head-mounted display (HMD), and projection-based cavernous virtual system (CAVE). Among the included studies, 15 used 2D desktop displays, 45 used HMDs, and 3 used CAVEs [50–52]. The two-dimensional display systems were mainly laptop or TV screens, and the main HMD devices included the HTC Vive series ($n = 16$) and a series from Oculus ($n = 13$). HMD was the most commonly used device type (82.8%) in the included studies. VR with an HMD provides greater immersion and spatial presence than flat screen displays and is more cost-effective than CAVEs [53]. The media types included 2D photos or videos, computer-generated VR (CG-VR), and 360-degree VR based on real scenes (360-VR). Among the included studies, 360-VR was the most represented form of virtual media (51.7%). For 2D media, 14 studies included 2D photos/videos, of which 8 studies used only 2D photos/videos, and 6 studies were used for comparison with other virtual media forms or real forests. Nineteen studies included CG-VR: fourteen used only CG-VR, and five were used for comparisons with other forms of virtual media or real forests. In addition, the form of CG-VR varied, with three studies using an off-the-shelf VR game (Nature Trek VR) [54–56], and one study using digitally twinned real forests after they were scanned [22]. For 360-VR, 30 studies included 360-VR, wherein 23 studies used 360-VR only, and 7 studies were used for comparison with other forms of media or real forests. Most used 360-VR (video), and only one study used 360-VR (photo) [57]. Two-dimensional photos or videos are primarily captured using cameras or web sources. CG-VR is mainly generated using modeling software (e.g., Unity 2019, Unity Software Inc., San Francisco, CA, USA) or by directly using released games. Sources of 360-VR included ready-made videos shot by the research team using panoramic cameras or those downloaded from the web (Figure 3).

Figure 3. Sources of virtual forests. (a) Example of 360-VR captured using panoramic cameras (e.g., insta360) [58]; (b) Virtual forest footage from the internet (e.g., YouTube) [59]; (c) CG-VR using modeling software (e.g., Unity 2019, Unity Software Inc., San Francisco, CA, USA) [60]; (d) Electronic games on platforms (e.g., Nature Trek VR) [54].

Several included studies considered differences between multiple exposure media, including comparisons between virtual and real forests and those between different virtual media (Table 1). Eight studies compared virtual and real forests: one compared real environments with 2D photos [61], two compared real environments with 360-VR [62,63], three compared real environments with CG-VR [22,64,65], one study compared real environments with 360-VR and CG-VR [66], and one study compared real environments with 2D videos and CG-VR [67]. An earlier study reported that although both 2D and real environments promote stress reduction, real environments rated significantly higher in terms of the degree of altered states of consciousness (ASC) and energy [61]. However, with advances in technology, virtual headgear has the potential to approach real nature
and enhance the potential benefits [68]. A study comparing real forests and 360-VR forests found that both types of exposure to nature increased physiological arousal, benefited positive mood levels, and were restorative compared with indoor environments without nature [62]. One study reported similar benefits from real forests and 360-VR in terms of memory and executive function [63]. A study comparing a digital twin’s virtual forest with a real forest exhibited no significant difference in increased relaxation [22]. Although another study also demonstrated no significant difference between real and CG-VR forests in terms of both increased vigor and stress relief, the effect size was slightly stronger over time in physical conditions [64]. Interestingly, another study confirmed that CG-VR forests were just as restorative as physical forest environments; however, virtual forests appeared to be more fascinating and coherent [65]. Comparative real and virtual studies can help us understand the extent to which virtual forests replicate the benefits of real forests [69], which is important for assessing the potential of virtual forests [66]. However, research findings are not always consistent, with most studies reporting that virtual nature provides almost the same psychological and physiological benefits as real nature [69,70]. However, a few studies have propounded that virtual forests are more fascinating and compatible than real forests [65]. In conclusion, the extent to which virtual forests replicate the health benefits of real physical forests and whether this varies by virtual type and mode remains to be determined [70].

Table 1. Number of articles on virtual versus real forests and comparisons between virtual media.

<table>
<thead>
<tr>
<th>Comparative Dimensions</th>
<th>Detailed Comparisons</th>
<th>Number</th>
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<tbody>
<tr>
<td>Comparison between real and virtual forests</td>
<td>on-set vs. 2D photo</td>
<td>1</td>
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<tr>
<td></td>
<td>on-set vs. 360-VR</td>
<td>2</td>
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<tr>
<td></td>
<td>on-set vs. CG-VR</td>
<td>3</td>
</tr>
<tr>
<td>Comparison between virtual mediums</td>
<td>2D photo vs. 360VR</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2D video vs. 360-VR</td>
<td>2</td>
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<tr>
<td>Comparison containing both of the above</td>
<td>on-set vs. CG-VR vs. 360-VR</td>
<td>1</td>
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<tr>
<td></td>
<td>on-set vs. CG-VR vs. 2D video</td>
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Seven studies compared the different types of virtual media. Although different virtual media play a role in reproducing nature, there may be differences among them. The main approach of relevant studies has transitioned from the use of still images to the use of dynamic media (e.g., video), interactive media (e.g., navigable), and finally to the use of fully immersive virtual media [71]. Four studies compared 2D and VR. Studies have demonstrated that highly immersive simulations can enable the perception of a higher quality of recovery than less immersive simulations, and that high levels of immersion can promote distance and perceptual fascination (360-VR vs. 2D laptop screens) [72]; however, another study reported that forest exposure in VR is ineffective in reducing stress when compared with 2D photographs [73]. Two studies described 360-VR and CG-VR comparisons. One of them reported that CG-VR forests were more emotionally restorative than 360-VR forests [66]; however, the other reported no difference between 360-VR and CG-VR forests in terms of generating a sense of presence, decreasing anxiety, or improving mood states. These results suggest that if the participants’ tasks are passive and do not require active exploration of the environment, then the use of 360-VR could be preferred because the development of 360° video is easier and cheaper than that required for computer-simulated environments [74]. Comparative multimedia studies are important to determine whether one (or more) should be recommended for recreation and treatment. Health authorities can compare the costs and benefits involved and provide guidance for different groups or situations [64]. However, studies between different media have also not reached consistent conclusions, and thus do not support the hypothesis that VR may be more effective and beneficial than traditional 2D media, which may be related to various factors such as video stability, luminance, and display content [70]. The most used
medium in the included studies was 360-VR, and although it can provide a panoramic view to the experiencer and is more immersive than 2D video, its interactivity is limited, as it is prerecorded. CG-VR is highly interactive; however, this medium requires computer graphics skills for 3D modeling, and importantly, 360-VR is not an effective way to create a 3D model. VR, a non-interactive virtual landscape, does not fully mimic natural experiences, and longer experiments may also affect the participants’ perception of control and boredom [75].

Technical characteristics are unique features that differ from those of real forest environments. The technical characteristics of VR may be directly related to the effectiveness of the natural experience. The primary relevant terms included presence, realism, immersion, and motion sickness. Presence describes the subjective feeling of a person in a virtual environment, and is generated by the experience that is induced by immersive VR technology [29]. Motion sickness can be considered a specific type of visually induced motion sickness (VIMS) [76], which causes symptoms such as eyestrain, nausea, fatigue, headache, blurred vision, and postural instability during virtual experiences. Among the included studies, 39.7% addressed these technical characteristics, including motion sickness ($n = 10$), presence ($n = 8$), realism ($n = 3$), system usability ($n = 2$), immersion ($n = 1$), and tolerability ($n = 1$). However, most studies did not focus on or report on technical characteristics.

Studies have begun to focus on comparative studies on the differences in virtual technologies, including control, realism, and stability. In terms of the degree of control, one study explored its impact over one’s own behavior during nature experiences. The results indicated that active self-navigation had more positive health benefits than navigation by a researcher for a natural experience [55]. Regarding realism, one study compared the differences between CG-VR realism and demonstrated that more realistic VR environments evoked more positive emotional and serene responses and a greater sense of presence [67]. The results of another study indicated that realistic forest environments were more effective than dreamy forest environments in relieving psychological stress [77]. Another study reported that exposure to a CG virtual forest resulted in significantly higher cognitive performance, perceived restorativeness, positive emotions, sense of presence, lower perceived stress, and simulator disorders (motion sickness) than an abstract control group (cylinders, spheres, etc.) [60]. In terms of stability, the results of one study revealed that HIGH-stability 360-VR had a lower severity of motion sickness symptoms compared with LOW-stability video; however, no differences were found between the two in terms of presence, perceived environmental restorativeness, enjoyment, and HR.

4.2.2. Forest

First, several studies have reported that exposure to virtual forests has more positive health benefits than that to virtual urban environments, including physical and mental health [78], creative thinking [79], restorativeness [80,81], and nature connection [82]. In addition, virtual nature has more positive effects on stress reduction and cognitive improvement than indoor VR controls [17,58].

Second, in terms of comparative studies on virtual forest features and categories, the features addressed in the current study include forest type [83], natural light level [84], wildness [85], biodiversity [86], forest density [87], stimulation level [72], and perception of the video (perceived as live or recorded video) [88]. A study comparing the stress-reducing effects of seven different types of virtual forest resting environments (structure, wood, wood with a bench, wood with a platform and bench, platform with trees, waterfall with trees, and pool with plants) demonstrated that most natural environments do not have a very significant effect on stress reduction [83]. A comparative study on different levels of environmental brightness in a virtual forest demonstrated that exposure to moderately bright natural light significantly reduced stress in participants [84]. Another study reported that wild woods were described as more exciting than parkland and tended woodland [85]. A comparison of multiple levels of forest biodiversity revealed that low-
biodiversity VR forests demonstrated the greatest improvement in most indicators of well-being [86]. A study reported that higher forest densities provide better physical and mental health benefits [87]. Comparisons of calming and stimulating nature scenes revealed that both triggered restorative outcomes through different psychological pathways, and stimulating nature scenes were more captivating and resulted in higher levels of presence [72]. One study even reported differences between naturally perceived live videos and recorded video media, suggesting that live videos had better attention recovery but the same stress recovery benefits [88]. This study echoes previous arguments that not only bottom-up (bottom-up) perceptual processes but also top-down (top-down) influences need to be considered when understanding how VR can be emotionally engaging.

In addition, the narrative of the forest environment story setting may have an impact on the effectiveness of the experience. In the design and optimization of virtual forest environments, the infusion of narrativity proves essential through the introduction of themes, role-playing dynamics, immersive audio elements, landscape variations, and interactive components [54,77,89]. Such meticulous design facilitates a cohesive and engaging storyline that increases participant engagement and fosters a more profound sense of presence in the virtual ecosystem, which in turn enhances the emotional experience [90].

4.2.3. Participants

Most participants in the included studies were healthy adults, with university students being the most abundant group. In terms of age and sex, two studies targeted older adults [91,92] and one study included middle-aged and older adults [93]. One study considered a sample of adolescents aged 14–19 years [56], one selected a sample of children [94], one included only males [50], and three selected pregnant women [59,95,96]. In terms of occupation, only one study included factory workers [97]. Subjects were also selected by mental health status, with one study selecting healthy adults with low natural connectedness (CN < 3.71) [82], one selecting older adults with cognitive or physical impairments [91], one selecting people who self-reported or were diagnosed by a doctor as suffering from stress or burnout syndrome [61], one selecting patients with generalized anxiety [52] (generalized anxiety disorder), and one selecting college students with mild-to-moderate anxiety and depression (stated anxiety and depression scale scores ≥40 and ≤60) [98]. Based on physical health status, one study chose breast and prostate cancer patients [99], one selected cancer patients in a treatment center [95], and one study included patients undergoing hemodialysis [100]. The number of included subjects ranged from 8 to 360. Although different types of participants were included in the reviewed studies, the most common type was healthy adults, particularly college students. Further large-scale trials are required to investigate whether similar effects are observed across a wider age range [40]. In addition to considering age, more research is needed to focus on specific populations, either occupationally or physically, who may be potential future users of virtual forest therapy and for whom it may be an effective way to engage in natural contact. Scholars have started focusing on the impact of individual characteristics. In addition to demographic characteristics such as age, sex, and education, the current study incorporates connections to nature and technology, as well as life experiences. The aspect of connection to nature includes nature connectedness [86,101,102], attitudes towards green spaces [103], landscape familiarity [75], nature experiences, and frequency of visiting nature [86,94,104]. The aspects of connection to technology, that is, familiarity with computers and VR, include VR experiences [50,56,67,93,100,105], gaming experiences [54], and knowledge of VR [106]. Life experiences include physical activity [94,104,107] and sleep quality [104].

4.3. Experience

The experience theme delves into the subjective and qualitative dimensions of individuals’ engagements with the virtual forest. It encompasses sensory stimulation, interaction, and dosage, providing insights into the experiential richness and perceptual
dynamics of the virtual forest exposure. This category serves as a bridge between the core elements and the subsequent effects, as it explores how participants interact with and perceive the virtual environment.

4.3.1. Sensory Stimulation

In the reviewed studies, sensory stimulation was revealed to be assessed in 3 studies as visual only, 39 as audiovisual, 5 as audiovisual olfactory, and 1 as a supersensory system; however, 9 studies did not specify whether sensory stimulation other than visual stimulation was performed. This study used visual stimulation as the primary natural virtual exposure experience. Auditory studies have demonstrated an apparently significant interaction effect between vision and hearing in virtual natural environments, with natural sounds contributing to increased parasympathetic activity and more effective recovery after virtually induced stress [50]. Another study revealed that realistic sounds increase preference and realism [108]. Studies have shown that increased olfactory stimulation in VR natural environments can help reduce negative emotions and stated anxiety levels [89], and one study even suggested that olfactory stimulation may promote stress reduction more than visual stimulation [57]. A research protocol using VR and fogging phytofungicides (volatile organic compounds that are found in forested areas) to simulate forest immersion therapy was developed by a researcher to introduce positive changes in two patient groups: breast and prostate cancer patients [99]. Studies have demonstrated better recovery after multisensory exposure to 360-VR nature compared with visual-only experiences, and subjects perceive two identical nature scene landscape components significantly differently when auditory and olfactory stimuli are removed [86]. Studies have also begun to explore and propose a surreal multisensory nature experience called Nat(UR)e, where, in addition to audiovisual stimuli, subjects are exposed to natural odors and somatosensory stimuli, including wind, heat, and vibration [109]. The current research trend is to move from a predominantly visual experience to a multisensory experience. Scholars have suggested that to clarify the mechanisms by which multiple forest factors affect health, each sense needs to be stimulated separately through artificial climate laboratory experiments to determine the potential health benefits of forests and reveal the health-enhancing mechanisms of forest exposure [40]. Current virtual forest research mainly reflects the visual and auditory components of forests. The olfactory component can be added to a certain extent, but touch and taste are senses that cannot be easily simulated using current VR technology [22]. Regardless of technological improvements, it is likely that immersive virtual nature will never fully replicate the multisensory experience of real nature [29]. Regardless of the limited sensory stimulation, virtual forests may still produce similar effects to real forests, as a few recently published studies have shown [62].

4.3.2. Interaction

The majority of subjects in the included studies were seated, with only a few studies involving other types of interactions. One study involved walking on a treadmill while wearing a VR mask [63], and another involved moderate-intensity aerobic exercise (cycling) in a CAVE virtual system [52]. A study that compared sitting and standing in a virtual environment reported an enhanced presence while standing [54]. Another study combined real physical activity with VR nature for children and found that physical activity followed by VR experience improved children’s attention levels [94]. Other studies simulated real forest walks in a VR forest using transient maneuvers [54,67,84]. Future research could consider incorporating more interactive designs into the virtual world to mimic real-world human behavior and allow subjects to become more immersed.

4.3.3. Dose and Duration

The duration of virtual forest exposure in the included studies ranged from 1 to 45 min. However, knowledge gaps remain regarding the effects of exposure duration on
health benefits. A systematic review revealed that virtual nature interventions lasting more than 10 min produced more consistent effects than those of a shorter duration [110]. However, the optimal viewing duration may vary across media formats. A study on the effect of various durations of a 2D video of a forest revealed that viewing for 20 min produced significantly better relaxation than viewing for 5 or 10 min [111]. A study focusing on the natural dose of 360-VR reported that a 5 min exposure produced greater stress recovery benefits than 1 and 15 min [75]. However, another study did not find any significant effect of viewing duration on participants’ transient stress or mood [56]. In virtual environments, there may be a relationship between the exposure duration and motion sickness. Determining the optimal viewing duration may aid the practice of virtual forest therapy in the future.

Most studies have focused on the short-term effects of VR forest exposure, with limited research on the health benefits or potential adverse effects of long-term exposure (n = 9). Short-term exposure is generally defined as a single experience lasting from a few minutes to a few hours or a full day, whereas long-term exposure is defined as exposure lasting more than a day [112]. The causal role of natural exposure in improving short-term impacts is well known; however, its influence on long-term physical and mental health is not entirely clear [49]. The longest of the included studies lasted 12 weeks (one exposure per week) [97], and the shortest lasted two days (three exposures per day) [96]. One study reported that participating in a VR forest experience for three consecutive days resulted in sustained psychological improvements in older adults [92]. In another study, where three 10 min virtual nature exposures were conducted over two weeks, the interventions were restorative, resulting in significant and gradual increase in CN, which was strongly associated with the enjoyment of and motivation to participate in nature in the future [82]. However, a few studies did not find sustained health benefits in all cases. In one study, where subjects viewed forest videos for five consecutive days during COVID-19 isolation, only a short-term decrease in anxiety levels was observed, but not in the long-term, highlighting the limitations of virtual experiences [113]. Another three-week virtual nature intervention study reported no further improvement in the physiological health of patients undergoing hemodialysis after repeated VR exposure [100]. This result may be owing to repeated exposures to the same forest video, which led to boredom in subjects. Diverse forest landscapes may help reduce boredom and provide long-term benefits. Scholars emphasize that long-term studies are crucial for testing the efficacy of virtual forests, and that the optimal intervention exposure period for VR-based naturopathic treatments is still undetermined; thus, more reliable studies are needed.

4.4. Effects

The effects category systematically examines the outcomes arising from virtual forest exposure, further subcategorized into individual-oriented benefits (physiological, emotional, cognitive) and connection-oriented benefits (social, environmental, transcendent). Negative effects, such as motion sickness, are also acknowledged. This thematic classification is proposed to explicate the diverse impacts that virtual forest exposure may exert on individuals across various dimensions, establishing a direct link between experience and its resultant effects.

This study drew on a previous approach to categorize effects and incorporate the negative effects of virtual environments [48]. The effects included individual- and connection-oriented and negative effects. Nukarin et al. [48] proposed a multidimensional restorative VR model of nature, including six dimensions: (1) physiological, (2) affective, (3) cognitive, (4) ecological, (5) social, and (6) transcendent. According to Maslow’s theory, as basic human needs are satisfied, a new set of needs emerges, forming a hierarchy. The first three dimensions listed above fall into the individual-oriented category and are oriented towards basic homeostatic needs, including survival, security, and competence. The other three belong to the connection-oriented category, which is related more to interactions with higher-order systems, that is, connections with other humans, the Earth, and
the universe. The model differs from traditional environmental psychology theories in that it expands the recovery effects to include connectivity with the outside world in addition to physiological and psychological health, which leads to greater holistic health benefits. The main negative effects include motion sickness owing to technological factors, discomfort because of the weight of the equipment, and fear of the forest.

Individual-oriented effects are of significant interest to researchers. Incorporated studies have reported extensively that virtual forests have positive impacts on physiological, affective, and cognitive effects. Common physiological measures include blood pressure (BP) [86,91,96], heart rate (HR) [93,100,103], heart rate variability (HRV) [97,100,114], electrocardiography (ECG) [97,100], skin conductivity levels (SCLs) [84,103], electrodthermal activity (EDA) [86,109], electroencephalography (EEG) [52,58,87], salivary cortisol [103], and salivary amylase [51,78,83]. Most studies used wearable devices for measuring these physiological factors. Common outcome indicators of affective effects include positive or negative affect [97,98,101,103], perceived stress [52,56,58], perceived restorativeness [60,72,93], mood state [93,96,98], and others. Such studies mainly utilized measurement scales such as the Positive and Negative Affect Schedule (PANAS), Perceived Stress Scale (PSS), Perceived Restorativeness Scale (PRS), Profile of Mood States (POMS), and State–Trait Anxiety Inventory (STAI). Cognitive effects, including short-term memory [60], creativity [115], attention [93,94,116], executive function [63], and cognitive performance [58,73], have been measured using various cognitive tasks, such as the Stroop color–word task, Sustained Attention to Response Test (SART), and Trail Making Test (TMT). Other tests include the Digit Span Backward (DSB) test, Necker Cube Pattern Control (NCPC) test, and Digit Span Memory (DSM) test.

Only eight studies addressed the connection-oriented effects of virtual forests, all of them related to ecological effects, whereas no study reported on social and transcendental effects. Outcome indicators of connection-oriented effects include nature connectedness [67,81,82,105], motivation to participate in nature in the future [82], and ecological behavior (pro-environmental behavior) [102]. Also included are perceptions of the environment, such as perceived naturalness [85], perceived environmental features [84], and perceived biodiversity [108]. The health benefits of connection-oriented effects may not be immediately demonstrable; however, their impact on post-exposure behavior may be more profound. People are increasingly looking for ways to combine their love for technology with that for nature [26]. Virtual forest interactions may prompt us to rethink the relationship between humans and the natural environment, evoke a sense of reverence for real-world nature, and promote environmentally friendly behavioral changes. Boomsma et al. outlined the motivational role of mental representations (mental images) in pro-environmental behavior, describing how these representations can transform abstract values into positive actions through the same process of elaboration. This theory highlights the key role of mental representations in determining behavioral outcomes [117,118]. This opens an interesting link to the use of VR technology, such as whether future attitudes towards nature and pro-environmental behaviors will change after a VR forest experience [51,82].

In terms of negative effects, a few restorative studies on HMDs reported negative effects such as mood deterioration and perceptual fatigue [119], of which motion sickness may be a significant factor [66]. Recent studies have demonstrated a negative correlation between motion sickness and the sense of presence [120]. Ten articles in the included studies reported motion sickness, but none reported fear of the virtual forest environments. Currently, two explanations have been suggested for its pathogenesis: the sensory conflict theory [121] and postural instability theory [122]. Research is ongoing to identify the factors that influence the level of motion sickness, such as movement style [54], camera stability [107], habituation, scene oscillations, motion lag, and exposure duration [29]. Further research is needed in the future to measure the incidence of physical and emotional adverse reactions that are reported by experiencers, as well as any discomfort or inconvenience associated with the VR equipment [123], which would help us further clarify the issue of the “tolerability” of virtual technologies.
4.5. Circulation

The circulation theme encapsulates the cyclical nature of individuals’ interactions with virtual and natural environments. Positioned as the concluding theme, circulation provides insights into the sustainability and long-term implications of the virtual forest exposure experience, thereby establishing a temporal and iterative relationship with the preceding categories.

The term circulation indicates the willingness to revisit virtual forests and visit real forests. This motivates people to spend more time in both real and virtual forests, constituting a virtuous circle and a connection with real forests. However, currently, two articles have reported a willingness in subjects to visit real nature [82,92] and one article reported the willingness to revisit VR and recommend it to others [59]. Notably, the benefits of virtual forests are limited (Table S2 [124]). The unique atmosphere, fresh air, and sounds of nature in real forests cannot be fully replicated. It would be gratifying if the virtual forest experience leads to more visits to real forests. This is because visits to real forests are bound to have a wide range of positive and far-reaching effects.

5. Discussion

We believe that an increasing number of virtual forest exposure studies will be conducted in the future as technology evolves. Developments in this area will provide additional tools and insights to deepen our understanding of how virtual forest environments affect human health, opening up new possibilities for future interventions and treatment programs. Several aspects of future research need to be refined.

Future research should emphasize interdisciplinary collaboration, particularly among computer science, medicine, and forestry-related disciplines, to deepen our understanding of the virtual forest experience [125]. Multidisciplinary collaboration can be achieved through integrated research across the three core elements of the field. For example, forestry scholars can provide insights into forest characteristics to help computer scientists provide better virtual environment simulations. Computer scientists can further improve VR technology and provide knowledge of additional technical features. Medical experts can scientifically determine the health outcome variables for multiple categories of people.

During the experience, the sensory stimuli of a real forest must be replicated to the maximum extent possible. Examples include hearing, smell, and touch in addition to sight [126–129]. For example, fenugreek and negative oxygen ions in real forests are important healing factors. There is a need to expand the posture parameter to include more behavioral interactions than just sitting, such as forest walks, rides, runs, and other green exercises. If virtual forests are used as medicine, the exposure dose (duration, frequency, etc.) should also be a topic of focus for future research [130].

Further studies are needed to explore the underlying mechanisms of the health benefits of virtual forests. There is still a gap in the research on virtual forest therapy versus real forest therapy. Current research on real forest therapy has explored the positive effects of forests on the immune system [131,132]. It has even reached micro-level physiological recovery mechanisms. For example, there is an association between short-term exposure to forests and heart rate variability and the mechanisms of molecular linkages [133], as well as effects of waterfalls and forests on the metabolism of choline and amino acids [134] and the mechanisms that suppress chronic stress [135]. However, mechanisms underlying the benefits of virtual forests remain unclear. More research on the mechanisms underlying the effectiveness of virtual forest therapy, as well as greater collaboration between disciplines, is needed in the future.

From the perspective of “evidence-based design” and “evidence-based medicine”, relevant research is important for green space planning, design, and forest therapy. Scholars advocate that future researchers should be able to share full-resolution VR forest videos or model files and build a database of VR forest stimuli that can be used for new or
replicated studies [136]. Several organizations and institutions are already using virtual forest experiences as a health intervention [137–139]. However, the heterogeneity of research in this area makes it currently difficult to develop specific practice recommendations [140]. More high-quality, exploratory, and in-depth research is needed to inform best-practice guidelines [141].

6. Conclusions

Unlike previous reviews that have focused on only one aspect of virtual forest exposure, such as specific health outcomes, our narrative review examined existing research on the effects of virtual forests from the perspective of the entire process of exposure. Owing to the diversity of studies, this study used a narrative review and not a systematic review to gain an understanding of the topic. The diversity of study designs, analytical methods, and health outcomes among the included studies on virtual forest exposure did not allow us to systematically assess the quality of the studies. However, based on the purpose of our study, the narrative review approach was reliable in describing the latest developments in the field as well as its current overall status. We proposed a conceptual framework for virtual forest exposure called “Core Elements-Experience-Effects-Circulation”. This framework focuses on core aspects of the entire exposure process. Not only does it consider technical features that are different from real forests, but the effects connect to real forests without stopping at virtual forests. The conceptual framework that we have proposed may be only an attempt at theoretical research on virtual forest therapy, the limited number of studies may make the framework miss certain key processes and details, and the diversity of studies suggests that the pathways through which virtual forest exposure produces health benefits may vary. We predict that further research will shed light on the recovery pathways and potential mechanisms of virtual forest exposure.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/f15010083/s1: Table S1: Search protocols for narrative review of virtual forest therapy; Table S2: Characteristics of the 58 studies included in the narrative review.

Author Contributions: X.J.: conceptualization, methodology, data curation, writing—original draft, and writing—review and editing. J.X.: methodology and data curation. Y.X.: software and visualization. H.L.: methodology and writing—review and editing. S.P.: visualization. B.Z.: project administration, conceptualization, and supervision. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Natural Science Research of Jiangsu Higher Education Institutions of China (No. 1020221108); Priority Academic Program Development of Jiangsu Higher Educations Institutions (No. 164120230).

Data Availability Statement: The data used in this study are included in the Supplementary Material, and any additional inquiries can be directed to the corresponding authors.

Acknowledgments: Figure 1 was modified from a PowerPoint template (By PresentationGO). We would like to express our gratitude to PresentationGO for providing the PPT template used in the creation of figures for this review.

Conflicts of Interest: The authors declare no conflicts of interest.

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