Review Article

Association Between Built Space and Cognition in Humans: A Scoping Review

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ABSTRACT

Background: Various built environment characteristics have been shown to have varied effects on mental health. There is evidence for a positive relationship between certain BE characteristics and mental disorders. The talk on cognition is inevitable in any argument on mental health. This review looks at various BE characteristics and cognition and their interrelationship.

Materials and Methods: A Boolean search of PubMed articles with keywords like 'built environment', 'built spaces', 'green spaces', greenspace,'neighbourhood environment' and 'attention', 'concentration', 'cognition', 'cognitive function' and 'cognitive disorders' was carried out and relevant articles were chosen by two individual investigators.

Results: 26 articles were chosen for the study, of which 22 were cross-sectional, 1 longitudinal, 1 cohort, 1 retrospective and 1 prospective study.

Conclusion: There is a lot of evidence for the positive correlation between green spaces and cognitive performance. Greenness, biodiversity, walkability has been investigated to show a beneficial effect on cognition, especially attention restoration. Longitudinal studies that include persons with comorbidities will help as better evidences for the above positive correlation.

Keywords: Built Environment, Built Spaces, Green Spaces, Walkability, Cognition, Attention

Running Title: Built Space and Cognition in Humans

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Built environment includes all man-made structures that constitute the space that we live and move in, like buildings, parks, malls, temples etc.[1] Built environment has shown to have a huge impact on different dimensions of human life, including thoughts, emotion and behaviour.[2] With the advent of studies on human-environment interactions, more research has been directed towards specific environmental characteristics and their impact on human life and health. The results from such studies have helped the humans to build sustainable and healthy environments which are ergonomically designed to improve productivity, reduce stress and facilitate behavioural changes.

Cognition is one of the core components of mental health and illness. Cognition is defined as the mental action or process of acquiring knowledge and understanding through thought, experience, and the senses.[3] The six domains of cognition are - complex attention, executive function, learning and memory, language, perceptual-motor function, and social cognition.[4] Cognition is needed not only for the complex intellectual processes

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such as abstract thinking and problem solving, but also for the normal functioning in day-to-day activities.

Cognition is affected in many of the mental disorders such as schizophrenia leading to various cognitive deficits including poor attention and executive function.[5] These cognitive deficits have a huge impact on the functional recovery in patients with mental disorders leading to poor quality of life and high caregiver burden. The emerging fields of cognitive neuroscience and cognitive psychology are trying to understand the basics of cognition and translation of these findings to improve cognition in normal people and remedial interventions for patients with cognitive deficits.

Various characteristics of the built environment have been found to have associations with different mental health dimensions including cognition.6 For example, the association of green spaces with lower incidence of stress and incidence of greater anomie in people residing in high-rise buildings highlight the importance of the built spaces in determining human emotion and behaviour.[7] Similarly, a properly designed built environment is helpful in the development of healthier children and healthier communities.[8] Biophilic environments have shown to have a positive impact on mental health. Biophilia is a term coined by Erich Fromm that points to intense love for nature. Biophilic design in architecture involves connectivity to nature through direct and indirect means.[9]

There is modest research on the relationship between built environment characteristics and cognition and fewer reviews on the same. However, there are no holistic reviews that address questions on all built environment characteristics and their impact on cognition. Hence, in this review, we have attempted to synthesize and summarize the studies that have examined the associations between built environment and cognition in humans.

MATERIAL & METHODS

Scoping reviews are those that enable us to map out the key concepts via research by using available evidence.[10] Through sequential steps, the scoping review process maps and synthesizes key underlying concepts in a particular field to identify disparities in existing knowledge.[11] The information extracted for this scoping review was, the author, sample of study, type of study, instruments used and major findings. Two research investigators screened a total of 453 articles for its relevance by title. This brought the number down to 62 articles. These 62 articles were subjected to another screening process. This time the articles were selected based on their relevance from the content of the abstract, leaving us with 32 articles. NCBI PUBMED was the search engine used to extract the relevant articles from MEDLINE Database. Initially, free and broadened search was encouraged, to pick out relevant articles. Key words such as: 'built environment & mental health', 'built environment & cognition', were used to identify the articles and draw out the common keywords. For built environment keywords such as "green space", "built space", "green environment" and "green space" were used. And for cognition, keywords such as "cognitive enhancement", "attention", "cognitive disorders" and "concentration" were used. Eventually, a combination of keywords: ("built space" OR "built environment" OR "green space" OR "green environment") AND (cognition OR "cognitive enhancement" OR "cognitive disorder" OR attention OR concentration) were searched in the PubMed Advanced search Builder in the field of 'text word'. Language filter was applied for articles in 'English'. All possible dates of publication were considered.

RESULTS

With the above-mentioned search terms, after adding filters for English language and excluding reviews, we got 453 articles for review. On further scrutiny 62 articles were selected based on relevance of title and 32 based on abstract. Finally, we included 26 articles in our scoping review **(Table 1)**. The studies mostly included samples from the general population, few samples from previous cohorts, school-going children and college students and public health registry. We had 22 cross-sectional studies, 1 retrospective, 1 prospective and 1 cohort study. The articles were grouped according to the cognitive function that was studied in the research, and we found most of the articles pertaining to attention and some on cognition in a broader sense. The studies also had heterogeneity in the built environment characteristics that were studied but the most common being greenness.

Table 1 Summary findings from the studies included on built environment and cognition

Author, Year	Type of study	Sample	Tools	Key findings
Wood et al., 2018[12]	Crosssectional survey	People entering the 12 parks located in Bradford (n=128)	NEST (Natural Environment Scoring Tool), 21 point Attention Restoration Theory questionnaire.	There is a positive association between site facilities and biodiversity. Restorative benefit is predicted by biodiversity, which explained 43% of the variance in restorative benefit across the parks, with minimal input from other variables. The benefits accrued through access to green space were unrelated to age, gender, and ethnic background.
Lin et al., 2020[13]	Cross sectional study	40 college students	Emotiv EPOC (excess post exercise oxygen consumption) + EEG (electroencephalogram) headset to dynamically measure 6 neuralemotional parameters: engagement, valence, meditation, frustration, focus, and excitement. ANCOVA to analyse pre-test and post-test variants	Walking in urban green space is more favourable for stress reduction. Sitting in urban green space is better for attention restoration.
Mygind et al., 2018[14]	Cross sectional study	47 children aged 10-12 years in school	Stress response by Heart-rate monitor. Cognitive performance by D2 test.	No evidence to support that the children's cognitive performances were improved in the natural environments compared to classrooms.
Reeves et al., 2019[15]	Cross sectional study	36 participants through social corporate responsibility	HR (heart rate) and EEG (electroencephalogram), DASS (depression anxiety stress scale) Holmes and Rake stress inventory, Nature relatedness scale	The EEG data showed modulation of high beta band activity only in the wetland setting, potentially related to changes in attention. Decrease in negative feelings in wetland setting observed in stressed individuals
de keijzeret al., 2018[16]	Cross sectional study	6506 participants' data from the Whitehall II cohort	Normalized Difference Vegetation Index; NDVI Reasoning, verbal fluency, short term memory.	Higher residential surrounding greenness was associated with slower cognitive decline over a 10-y follow-up period in the Whitehall II cohort of civil servants.

Zijlema et al., 2017[19]	Cross sectional study	Between n=1493 and n=1602participants for the current analyses out of 1628 participants who completed the CTT	Colour trails test (CTT) for assessing cognitive function	Each 100 m increase in residential distance to NOE was associated with a longer CTT completion time of 1.50% (95% CI 0.13, 2.89). Higher loneliness and more air pollution worries were associated with longer CTT completion time, while higher social cohesion and better mental health were related to shorter CTT completion time.
Dadvand et al., 2018[20]	Cross sectional study	253 school children without special needs	Normalized difference vegetation index (NDVI), n back test, Attentional Network Task ANT, 3D MRI (magnetic resonance imaging)	Brain regions with larger volumes in urban children with higher lifelong exposure to residential surrounding greenness, especially those involved in cognitive functions.
Markevych et al., 2018[21]	Cross sectional study	66,823 children, all beneficiaries of the health insurance company AOK PLUS and born between 2000 and 2004	MODIS (moderate resolution imaging spectroradiometer) Normalized Difference Vegetation Index (NDVI)	A 0.1-unit increase in NDVI decreased the relative risk of ADHD by a factor of 0.82. An increase of PM10 and NO2 by 10µg/m3 raised the relative risk of ADHD by a factor of 1.97 and 1.32, respectively.
Ward et al., 2016[22]	Cross sectional study	108 participants aged 11–14 years from three intermediate schools in Auckland, New Zealand	Computerised neurocognitive testing was conducted using CNS (central nervous system) Vital Signs	No significant association between green space exposure and cognition.
Tiesler et al 2013[23]	Crosssectional study	1,932- 10 year old children with complete exposure to green space.	Behavioural problems -Strengths & Difficulties Questionnaire. Access to green space – distance to nearest green space.	Poor access to urban green spaces associated with behavioural problems, hyperactivity/inattention problems. More significant in male children. Access to forests unrelated to children's mental health.
Bodin et al., 2015[24]	Cross sectional study	2612persons of Malmo, Sweden.	A residential environment survey	Access to a quiet side (facing yard, water or green space) was associated with reduced risk of annoyance & concentration problems. Bedroom window facing the same environment was associated to better sleep

Donovan et al., 2019[25]	Longitudinal study	923 eligible children born in 1998 in New Zealand who were selected using IDI (Integrated Data Infrastructure).	Exposure to green space estimated using -Normalized Difference Vegetation Index (NVDI).	Increasing lifetime exposure greenness reduces risk of ADHD.
Sharp et al., 2019[26]	Cohort study	A cohort of 190 children (96 with ADHD).	The 190 children had a range of neigh-bour-hood& familial factors ascertained & had repeated clinical assessments over an average of 2.5 years at a U.S. research centre. Using mixed model regression, they found an association between neighbourhood wealth & inattentiveness. Using transactional model, they checked if familial processes, influence the results.	Children in relatively affluent neighbourhoods showed improvement with age in inattention, largely independent of variation in a wide range of familial factors such as family conflict, family educational/economic status. Children living in less affluent neighbourhoods showed clinical deterioration only if the family had high levels of conflict or if the parents were of lower economic/education status.
Allen et al., 2016[27]	Cross sectional study	24 Participants who spent 6 full working days (9am – 5pm).	On different days, they were exposed to IEQ (indoor environmental quality) conditions representative of Conventional [highconcentrations of volatile organic compounds (VOCs)] andGreen (low concentrations of VOCs) office buildings in the United States. Additional conditions simulated a green building with a high outdoor air ventilation rate (labelled Green+) and artificiallyelevated carbon dioxide (CO2) levels independent of ventilation.	On average, cognitive scores were 61% higher on the Green building day and 101% higher on the two Green+ building days than on the Conventional building day ($p < 0.0001$). VOCs and CO2 were independently associated with cognitive scores.
Gao et al., 2019[28]	Cross sectional study	120 healthy Chineseparticipants voluntarily Recruitedvia 'WeChat'	Randomly divided 20 participants in a group,exposed to one of the 6environments via Virtual Reality. EEG (electroencepha-logram) – to measure physiological stress.	Restorative effects on attentional fatigue and negative mood using VR (virtual reality) was seen. Partly open green (POG) space has a significant effect on negative mood regulation.

			Profile of Mood States(POMS-SF) scale - used to measure psychological stress.	A strong positive correlation was seen between preference of an environment and positive mood. Blue & green spaces have restorative effect
Amoly et al., 2014[29]	Cross sectional study	2,111 school children (7-10 years of age) from 36schools in Barcelona in 2012.	Data on: Time spent in green spaces and beaches and Strengths and Difficulties Questionnaires (SDQ) from parents & ADHD/ DSM-IV questionnaires from teachers. NDVI used to define greenness.	Significant inverse associations between green space playing time and SDQ total difficulties, emotional symptoms, and peer relationship problems; between residential surrounding greenness and SDQ hyperactivity/inattention and ADHD/DSM-IV total and inattention scores; and between annual beach attendance and SDQ-total difficulties, peer relationship problems, and pro-social behaviour. For proximity to major green spaces, the results were not conclusive.
Amicone et al., 2018[30]	Cross sectional study	82 primary school children between 4thand 5th grade in middle urban area of Rome, Italy.	Study 1- morning recesstime, team play was allowed in natural environment. Study 2- afternoon recesstime, team play was allowed in built environment.	An increase in sustained and selective attention after the natural environment condition and a decrease after the built environment break. Higher scores in perceived restorativeness were registered after the natural (vs. built) environment condition. Team standardized playtime and individual free play recess in natural environment (vs. built) support pupils' attention restoration during both morning and afternoon school times, as well as their perceived restorativeness of the recess environment.
Cherrie et al., 2018[31]	Retrospective study	281 participants of Lothian birth cohort.	At mean age 78 - a standalone questionnaire was administered. At mean ages 11, 70 & 76 – the Moray House Test no.12 (MHT) was administered to test cognition.	Neighbourhood provision of public parks from childhood through to adulthood may help slow down the rate of cognitive decline in later life.

			Other genetic,demographic and socio-economic information was collected via questionnaires.	The association between childhood and adulthood park availability and change in the Moray House Test Score from age 7 to 76 was strongest for women, those without an APOE e4 allele.
Dadvand et al., 2015[32]	Cross sectional study	2,593schoolchildren in the 2nd to4th grades (7-10 years) of 36primary schools in Barcelona, Spain (2012-2013).	Greenness – NDVI (normalized difference vegetation index) and cognitive development computerized attentional network test.	Beneficial association between exposure to green space and cognitive development among schoolchildren that was partly mediated by reduction in exposure to air pollution.
Crous-Bou et Al., 2020[33]	Cross-sectional study.	958 middle-aged, cognitively unimpaired subjects, many of them offspring of Alzheimer's Dementia (AD) patients.	To study airpollution-European Study of Cohorts for Air Pollution Effects (ESCAPE). Greenness- NDVI Cognitive development-Memory Binding Test (MBT), Wechsler Adult Intelligence Scale. (WAIS)-IV, Preclinical Alzheimer Cognitive Composite (PACC), MRI Scan	No significant associations were observed between urban environmental exposures and the cognitive composite (> 0.1). Higher exposure to air pollutants, but not noise, was associated with lower cortical thickness in brain regions known to be affected by AD, especially NO2 and PM10. Increasing greenness indicators was associated with greater thickness in these same areas
Dadvand et al., 2017[34]	Prospective study	Based on data from 2well established population based birth cohorts in Spain.	Greenness- NDVIConners' Kiddie Continuous PerformanceTest (K-CPT) at 4-5 years (n=888)and the Attentional Network Task (ANT) at 7 years (n=987).	Children who had more exposure to green space had lesser omission errors in the K-CPT and ANT. Associations with residential surrounding tree cover also were close to the null, or were negative (for ANT HRT-SE) but no statistically significant.
De Vries et al., 2016[35]	Cross sectional study	6621participants. Dutch speaking 18-24 year olds.	Health data were derived from a nationally representative survey (NEMESIS-2). Composite International Diagnostic Interview (CIDI), version 3.0. Mental Health Inventory-5 (MHI-5). Dutch Land Use database, LGN6 - assess green space.	Associations were generally stronger for blue space than for green space, with ORs up to 0.74 for a 10%-point increase.

Besser et al., 2018[36]	Cross sectional study	4539 participant's from the Multi-Ethnic Study of Atherosclerosis	Cognitive measure-MESA's (multi ethnic study of atherosclerosis) Exam dedicated to residences or retail was calculated by dividing the Residential/retail area by the total buffer area	Increasing social destination density, walking destination density, and intersection density were associated with worse cognition, whereas increasing proportion of land dedicated to retail was associated with better processing speed. Certain characteristics in dense urban environments may have a disproportionately negative association with cognition in vulnerable populations. APOE ε2 carriers may be more susceptible to the potentially beneficial effects of denser neighbourhood BEs on cognition.
Kodama et al., 2010[37]	Cross-sectional study	18 patients with traumatic brain injury and 18normal controls	WAIS III (Wechsler's Adult Scale Intelligence),P 300 - Trail-making test.	TBI (traumatic brain injury) patients showed a smaller amplitude of P 300 in the red environment than control subjects. In patients, P300 latency was significantly shorter in the green environment than in the other colour environment. Rehabilitation intended to improve selective attention or information processing speed might be more effective if performed in a low anxiety environment (i.e., a green environment).

DISCUSSION

Built environment and cognition

Ng et al., observed that there was a positive and significant association between land use mix diversity, walkability and repeatable Battery for the Assessment of Neuropsychological Status (RBANS) z score, immediate and delayed memory, recall, visuospatial and constructional ability but not attention.[18] This is in contrast to the attention restoration theory of Kaplan. Allen et al., showed better cognitive scores in people having 1 or 2 green building days in their workspace.[27] Ward et al., found no association between greenspace exposure and cognition as measured by computerized CNS vital signs.[22] Besser et al., found association between denser urban environments and worse cognition.36Dadvand et al., 2015 had shown better cognitive development in children in green spaces.[32]

de Keijzer et al., showed slower cognitive decline in people exposed to greater residential surrounding greenness over 10 years; especially in the reasoning and fluency tests and not in short term memory.[16] Mediation analysis of three potential mediators (physical activity, social support, air pollution) for this association suggested no mediation. Provision of public parks in childhood and early adulthood is associated with lesser cognitive decline according to Cherrie and colleagues.[31] Wu et al., (2017) had shown that living in areas with higher

land use mix is associated with 30% decreased odds of cognitive impairment.[17] No significant association has been found between PACC and exposure to urban environments according to Crousbou and colleagues.[33]

Besser found that the association between natural environment characteristics and cognitive decline is associated with APOE2 and not with APOE3 or 4.[36] According to Dadvand et al., there is an association between lifetime greenspace exposure and larger brain volumes, especially the right and left prefrontal cortex.20Crousbou et al., have shown greenspace to be associated with higher cortical thickness in the brain and air pollution the converse.[33]

All studies on cognition have been cross sectional studies or studies taking samples from larger cohorts wherein there is a possibility for bias. The results of studies on greenspace and cognition are not comparable as there is heterogeneity in testing of cognition. Studies on cognitive decline have no matching for possible physical and psychiatric comorbidities that might increase the risk of cognitive impairment. Overall, the studies lack investigation on long term memory, executive functioning, social cognition or perceptual motor functioning. The very intrusive nature of an objective 'cognitive function' testing after brief exposure to any environment is not devoid of the confounder of performance anxiety and bias.

There might be a complex interaction of multiple factors in the association between green spaces and cognition. Oliver Mytton et al., have found a positive correlation between green space and physical activity and physical activity.[38] This mediates better cognition and neuroplasticity through epigenetic mechanisms.[39] Thus, physical activity may be an important mediator in the effects of green space on cognition. Various studies have proven green spaces to reduce state anxiety and cause stress recovery. It is also known well that stress and anxiety have a dual role on cognition,[40] but higher the anxiety, lower the cognitive performance.[41] Probable mediators for attention restoration in greenspace like anxiety in green environment versus other built spaces and their effect on EEG high beta band and P 300 latency offer insights into mechanisms behind such restorative benefits as expressed by the above studies.28

Attention restoration and green space

A study by Lin et al., observes 6 neutral emotional parameters. Out of the 6, only valence and meditation show consistent results.[13] The "valence" & "meditation" parameters are higher in participants who were walking (M=0.71 & 0.58) in green space, when compared to participants who were sitting (M=0.63 & 0.33) in green space. Whereas, the "focus" parameter showed a small contrary result of (M=0.55) in the sitting group which is higher than (M=0.42) in the walking group. Gao et al in their study subjected the participants to 6 different environments through VR. It was observed that there was no significant impact of the exposed environments on restoration of attention fatigue or positive mood. "open-green space" environment showed restorative effects of negative mood.

Both of the studies have been carried out in a short time frame. A better understanding of the same can be achieved by conducting long term studies. In the study by Gao et al., VR technology was used to expose the subjects to green spaces. Adopting technology to study the effect of green environment may not give authentic results when compared to studies that use natural environments.[28]

Attention restoration & natural/built environment

Wood et al., used the attention restoration theory (ART) questionnaire in their cross-sectional study. It was found out that, out of all factors (such as site facilities), biodiversity played an important role in attention restoration by 43%.[12] In another study, Amicone et al., divided the children into 2 groups. The first group that was given recess break in the natural environment, showed improvement in "sustained and selective-attention". The students' score in Bell's test was higher after the recess (M=32.61) than when compared to before the recess (M=31.85). The other group of students, who were given recess breaks in the built environment, showed no significant results.[30]

The above 2 studies were carried out with a local residential population. Therefore, it cannot be referred to show any ethnic, social or cultural differences. To get more holistic results, a much more random population can be taken and tools that meet standard criteria can be used.

Inattention/hyperactivity/ADHD and green space

A cross sectional studyshowed that children's behavioural problems were associated with their access to green space.[23] Using the Strengths & difficulties questionnaire, the behavioural problems were assessed. Children who had more behavioural problems such as mainly: hyperactivity or inattention were not exposed much to

green space. It was also found that there is no association between exposure to forest area and behaviour. Donovan et al., found out in their longitudinal study that, children who lived in rural areas, after 2 years of age were less likely to develop ADHD. Their odds ratio was found out to be 0.607. Exposure to rural living or NDVI only for the first 2 years of life did not decrease the risk of developing ADHD.[25] Amoly et al., in their cross-sectional study observed that there was a significant inverse relationship between exposure to green spaces and the scores in SDQ & ADHD questionnaire (DSM IV).[29]

In the 3 studies above, Amoly et al., & Tiesler et al., use the Strengths & Difficulties Questionnaire to study the behaviour and hence the findings can be compared.[23, 29] Amoly et al., & Donovan et al., used normalized difference vegetation index (NDVI) to measure greenness which gives more uniform findings.[25, 29] The drawbacks of Amoly et al., & Tiesler et al., are that they are cross-sectional studies. They need more evidence to back up their results.[23, 29] These 2 studies can be supported using Donovan et al. Their study is a longitudinal study. This way the findings of each study can be contrasted and compared to establish a link and further give it more value.

ADHD and neighbourhood environment

Among 190 children in a cross-sectional study, 96 were diagnosed with ADHD/inattention. 47% of these children showed improvement of symptoms with age.[26] This study also shows that children in neighbourhoods that are rich and affluent showed less clinical symptoms of ADHD.

This cohort-study has studied the influence of neighbourhood on children with ADHD. While doing so, it is known that neighbourhood factors are vast and cannot be controlled. Sharp et al have considered only a few baseline factors and hence the results do not give us a better understanding of the study. No standard tools were used to measure these factors. This study has to be associated with others that study familial and neighbourhood factors to give its results more evidence and value.

Selective attention and green space

Kodama et al. in their study showed that, in patients with TBI, P300 latency was significantly shorter in the green environment than in darkness ($p < 0.01$).[37] Rehabilitation intended to improve selective attention or information processing speed might be more effective if performed in a low anxiety environment (i.e., a green environment).

ADHD and pollution

Markevych et al., in their study observed that a 0.1 increase in NDVI decreased the risk of ADHD by a factor of 0.82. They also saw that an increase in PM10 & NO2 raised the risk of ADHD by a factor of 1.97.21 In the study, no proper information on SES and psychopathology of the family to assess risk of ADHD were found out. Understanding information of these factors will help in achieving a more holistic view of the results.

Concentration and quiet side

In another study, Bodin et al., observed that most participants were annoyed due to the noise and pollution from the traffic.24 Those who had bedrooms facing a green space had less concentration problems as they had proper sleep. This study lacks socio-demographic information. Further on, they use self-report questionnaires to assess the level of pollution. This can bring the possibility of bias.

Conclusion

The role played by spatial cognition in the various cognitive domains is of paramount importance in assessing the impact of environment on cognition. The study of such interactions is essential for building cognitively enhancing residential and workspaces. Architectural models that incorporate research findings on spatial cognition could be utilized for better living spaces.[42] Virtual reality implementation to simulate natural environments in an urban setting is a new idea in ergonomics to enhance cognitive work performance.[43] Such studies also provide insight into the psychopathology behind cognitive disorders, the role of environmental factors in the development of a cognitive disorder and ways to mitigate disability in the same. The close relationship between cognition and behaviour warrants a liaison with environment-behaviour studies (EBS) in this regard.[44]

There is a lot of evidence for the positive correlation between green spaces and cognitive performance.[45] The most common dimension studied is attention. The heterogeneity in testing of cognition makes meta-analysis difficult. The possible mediators of positive effects of greenspace and built environment

characteristics on cognition need further investigation. Longitudinal studies that include persons with comorbidities will help as better evidence for the above positive correlation. Greenness, biodiversity, walkability have all been investigated to show a beneficial effect on cognition, especially attention restoration.

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