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Neuroscience and the Cities: Neurourbanism

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Abstract

Cities are settlements where many people live together and whose population is constantly growing. Due to the rise of urbanization, the number of buildings in the cities has increased rapidly. The structures in the cities have been designed quickly and at low cost, often without considering human emotions and health. It has been observed that most of the people living in the cities have faced with some physical, mental and spiritual problems resulting from some aspects that have been ignored in the buildings or urban planning. In recent years, it has been pointed out that human health should also be taken into account when planning cities. The concept of neurourbanism emerged when neuroscience, which is an interdisciplinary branch of science, became the target of urban studies. Neurourbanism gives information about how an urban design consisting of healthy people should be, by measuring and detecting the changes created by different urban spaces on the human body. In this study, the design criteria to be considered in a healthy city are discussed under four main headings: “navigation, nature interaction, embodied experiences, and environmental stressors and mental health”.

1. INTRODUCTION

Despite having a long history, cities developed slowly until the beginning of the 19th century. During the industrialization period, that development accelerated, and cities began to grow rapidly [1]. People have migrated from rural to urban areas with the desire to earn more money, to live in a better-quality place, to have easier access to education, health and social services. That situation has increased the need for housing and revealed the importance of planning a city. The population of big cities are still increasing with immigration [2]. It is predicted that more than half of the world's population will live in cities in 2050 [3] . It is very important that people's feelings, health and happiness should not be ignored in the design of places where so many people live.

Since the beginning of human history, our living spaces have affected us on both cognitive and emotional level. Therefore, the urban life is extremely important for our physical and mental health as well as our quality of life. Due to the fact that construction costs, functionality and efficient use of space have gained importance in 20th century; modern cities have more mechanistic design than ever, providing less opportunity for human-nature interaction [4]. Also in Turkey, aesthetic traditions have left behind in the same period [5]. The number of monotype, concrete structures that are not given priority to lighting and ventilation, whose dimensions are not compatible with human dimensions, that are not nature-interactive have increased rapidly in number [4]. The architectural structures using city-specific natural materials and providing a sense of “where on earth we are" have now been replaced by modern structures which are ubiquitous or extremely creative but lacking aesthetic qualities [6]. The inherent beauty of natural elements used in architecture has been overshadowed by the modern world [6].

In recent years, the flaws of this approach on human life have begun to be understood. The studies have shown that the risk for developing depression, anxiety and schizophrenia may increase drastically by moving from rural areas to cities [7]. Not only mental disorders but also cardiovascular diseases have

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become more common with rapid urbanization [8]. So, what makes some cities healthy to live? How should city life be designed, which makes us be healthier, happier, more peaceful, creative, and productive? Research from a variety of disciplines agree that neuroscience may offer a new perspective to answer these questions. As a multidisciplinary field, neuroscience studies the nervous system which controls our perception of space, makes possible to find a place and direction, to have emotional reactions and aesthetic judgments [9]. With the architecture being the target of neuroscience, "neuroarchitecture" was born with the aim to create environments that can optimize human health and well-being [10,11]. Also in recent years, the concept of neurourbanism has emerged as the intersection point of neuroarchitecture and urban research [12,13].Gestalt psychology, environmental psychology, biology, cognitive sciences, experiential architecture, and urban planning contribute greatly to this interdisciplinary area [10]. In neuroarchitecture and neurourbanism research, brain imaging and stimulation methods such as electroencephalogram (EEG), functional magnetic resonance imaging (fMRI) as well as physiological measurements like galvanic skin response (GSR), heart rate variability (HRV), pupilometer, eye tracking are used [14]. Recently used augmented reality (AR) and virtual reality (VR) applications also offer promising results on why and how we are physiologically connected to a place [15]. With all these scientific methods used, neurourbanism aims to establish the relationship between sensory experience and architectural perception and to create a healthy urban life [14].

2. URBAN DESIGN CRITERIA PROPOSED BY NEUROARCHITECTURE

The components of the city are buildings, open spaces such as streets, parks, squares, and people. Cities are formed when the mentioned spaces come together after the design processes. The designs of the buildings thus form the architecture of the cities. Neuroarchitecture explores the impact of the design of structures on people and aims to create environments that can optimize human behavior, health and well-being (Ritchie, 2020). In addition to buildings individually, the design of cities also affects our brain.

This paper highlights some design criteria for a healthy urbanization based on recent research, which have an impact on the human brain in urban design. These are navigation, nature interaction, embodied experiences, and environmental stressors and mental health. We can also call these, the criteria of neurourbanism.

2.1. Navigation

Being able to find our way easily within a city is one of the major criteria that neuroarchitecture give importance to. We basically use two strategies to orient ourselves in space: egocentric (route based) and allocentric (map based) (Figure 1) [15]. Parietal, and frontal brain areas are important in egocentric perception, while occipital and temporal areas are important in allocentric perception [16] (Figure 2, 16). We take our own body in the center to navigate through in egocentric process. On the other hand, object-to-object relations matter in the allocentric process [18]. Egocentric people need signs and symbols, whereas allocentric ones need global compass information [18]. For instance, the blind has egocentric perception, and they need a route based designed city to live [15]. Thus, the cities should include appropriate signage and maps, especially for the transport systems where the navigating is complicated, in accordance with both principles, so that individuals can orient themselves by creating a proper cognitive map and have a positive urban experience.

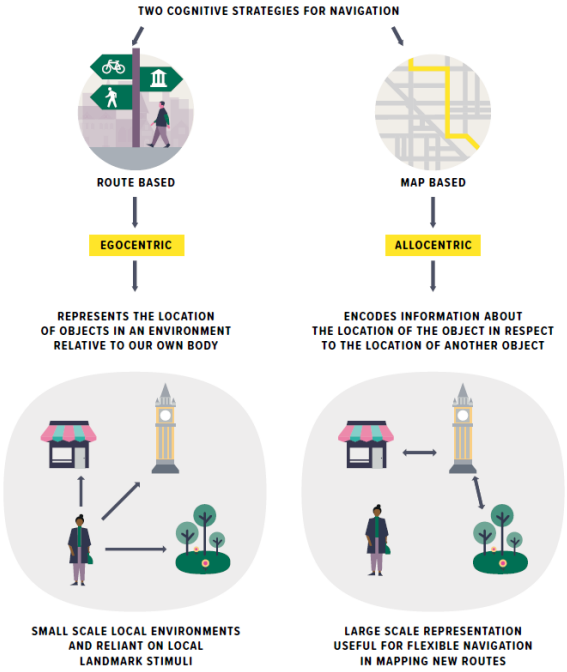

Figure 1. *Egocentric and Allocentric Processes of Navigation* [15].

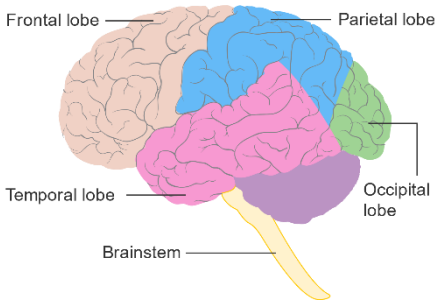

Figure 2. *The Four Lobes in Each Cerebral Hemisphere* [17].

Since spatial cognition and emotion processing mechanisms work closely in the temporal lobe of the brain, anxiety state may arise in cases of being lost [18]. This phenomenon is called disorientation stress or spatial unease [18]. Feeling lost and not belonging to a place can be seen as desynchronized brain waves (decreased theta/alpha ratio) in EEG [19,20). Spaces that have limited information regarding navigation like subway stations may elicit disorientation stress [18]. Exits and entrances areas well important to feel spatial ease [18]. Rotational buildings/spaces are also confusing to build cognitive maps, whereas mirror symmetry is much preferred for orientation (Figure 3) [18]. Aside from these, the use of wide streets in the city will make it easier to find directions [13]. Therefore, cities should be designed to facilitate navigation.

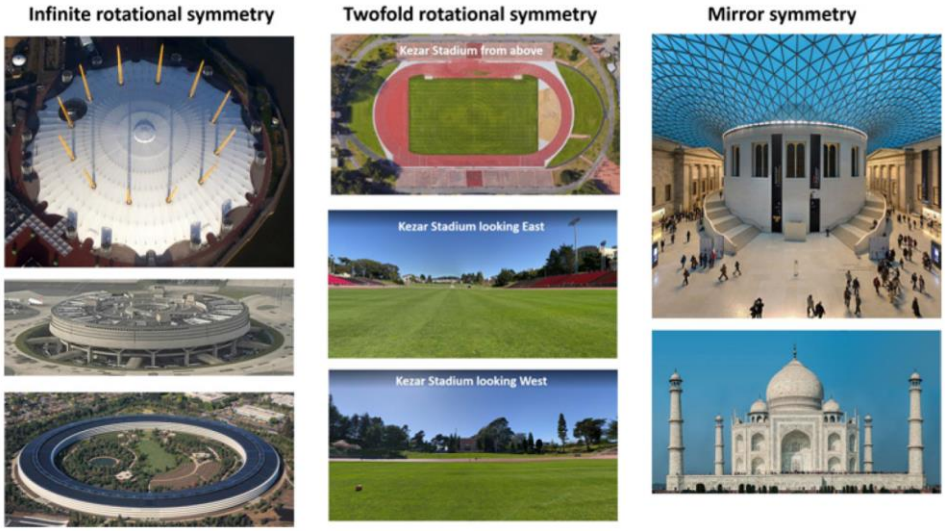

Figure 3. *Rotational and Mirror Symmetry Examples* [18].

2.2. Nature Interaction

The positive impact of having more greenery in the cities on our mind-body system has been known for years. Psychology studies have relied on self-reports to understand how nature make people feel [15]. Now with the help of neuroscientific data, we can understand how having more nature interaction in urban life benefit us at a biological level. To begin with, the concept of including nature in design became popular with the Attention Restoration Theory (ART) developed by Stephen Kaplan [21]. He also first used the term “biophilia” [22]. ART explains that our sensory systems are highly sensitive to the stimuli of living or life-like forms in nature and that the natural environment is perceived by the bottom-up processes of the nervous system [21]. ART also draws attention to the healing power of nature elements in design on emotional and physiological health [22,23].

Biophilic environments often use uneven surfaces and borders, curved walls, dynamic and diffused light and shadow of varying intensities that mimic nature, lower tone levels (more yellow-green content than

blue-violet content), and higher variation in color saturation (Figure 4). Minimally processed natural stone and wood materials are essential elements of biophilic design. Outdoor natural stone elements and nested fractals are also characteristic of biophilic design. Medium-to-high complexity fractal light patterns are more aesthetically pleasing than other patterns. Outdoor plants are another recommended biophilic element, which includes odor and visual components [22] (Figure 5). It was found that the pleasant time spent in the parks was increased depending on the tree density [19]. Furthermore, it has also been understood that the quality of the nature elements is important as much as the quantity [24]. Recently, nature in its wild form is suggested in cities. It seems like spontaneous vegetation is better for mind compared to cultivated greenery [25]. Wild urban nature can be included not only in parks, but also in roadsides, footpaths, and other public places (Figure 6) [25]. Besides, green areas can be created on the facades or roofs of buildings. This will also be a precaution against the increasing temperature due to global warming [26]. As the cities filled with reinforced concrete buildings, having more natural elements in built environments is a crucial [22]. In this sense, adaptive urban ecologies might solve the existing problems in our ecosystem [25].

Figure 4. *Curved Walls and Natural Stone Usage in Park Güell, Spain (photo belongs to the author).*

Figure 5. *Outdoor Plants as Biophilic Elements, a) b) Azerbaycan, Bakü Caspian Seaside c) Spain, A Coruña Square (photos belongs to the author).*

In addition, AR and VR studies have shown that the more we are exposed to the nature the more our autonomic nervous systems show strong relaxation responses [27]. While the cities giving more opportunities for human-nature interaction reduces stress and anxiety, they also increase brain region activation for empathy and love [28]. Moreover, it has been shown in many studies that biophilic forms in architecture are perceived more aesthetically than artificial designs [4,29]. Also in VR studies, environments containing nature elements were associated with higher HRV values and beneficial brain wave patterns in EEG compared to cityscapes. fMRI studies also confirms that the reward circuitry in the brain is also activated when exposed to nature city scenes. That means our nervous system is more responsive to a "green" city. Therefore, it is certainly better to frequently encounter green spaces, especially wild ones, in our daily lives to have a meaningful and restorative city experience [25].

Figure 6. *Wild Greenary (photo belongs to the author).*

2.3. Embodied Experiences

Mindful and bodily interactions with our surrounding is called embodied experiences. Embodied experiences are critical for a person to create meaning [30]. Diversity of experiences are of utmost importance for that meaning-creation process. Furthermore, the ultimate way to have diverse urban experiences is by triggering our senses such as sight, hearing, smell, and touch [25]. For example, the sight and sound of water evokes feelings of calmness, comfort, and privacy, lowers the stress level and increases

the sense of belonging to the place [23]. For these reasons, cities near sea, ocean or streams might be preferrable [23]. Fountains and pools in city squares also serve the same purpose [23] (Figure 7). Scents are also extremely effective in recalling past life memories and attributing emotional meanings to cities [28]. Moreover, new attempts try to include the sense of taste in urban design. Edible green infrastructure projects (Urban Food Street) have been successful so far for multisensory engagement with nature (Figure 8) [31]. Besides, the plants with different color, smell, texture in these green infrastructures may help individuals have a multisensory interaction with the nature and experience biodiversity [25]. The cities need more initiatives like this offering an alternative way for the city dwellers to engage nature in their daily lives.

Figure 7. *a, b, c) Barcelona, Spain d) Azerbaijan, Squares with Pools Sculptures and Greenary (photos belongs to the author).*

Figure 8. *Urban Food Street Project* [31].

Vitality is also another evoking factor for us to have diverse experience in an urban area. Recent reports indicated that human beings show great interest in liveness [32]. Additionally, responding towards the signs of vitality elevates our mood and keep us away from urban loneliness [33]. One vitality example from urban life might be public arts. An intriguing study has displayed that city dwellers paused often in front of the street arts [32] (Figure 9). These artworks make our 'autopilot' mode off, change the focus of our attention, and invites us to think creatively. Another example would be the interactive use of walls, fences, or facades of the buildings [32]. Rather than seeing these structures as barriers in a city area, attractive looks, and textures of them can move us away from the monotony of our lives and encourages us to move and explore [33] (Figure 10). In addition, an increase in the number of neurons in the brain has been detected with the discovery of new and different elements in a city [19,20]. Designing an enriched environment with different textured objects are quite beneficial for the development of children, too [34]. Thus, an effective city tour may be the one in which we feel the sun and wind on our skin, the texture of the ground and the walls, to hear the sounds near and far, smell the flowers around, see the aesthetic buildings along the way and checking the eye-catching street arts.

Figure 9. *Street Arts in a Square of Spain (photo belongs to the author).*

Figure 10. *Different Textured Facades, Spain-Barcelona Streets (photos belongs to the author).*

2.4. Environmental Stressors and Mental Health

In order to build conscious and healthy cities, we must mitigate the environmental stressors such as noise, light, and air pollution [15]. First, noise pollution is a situation that threatens our cognitive health. Decreased productivity in working area [35], headaches and high stress reaction in children are observed due to excessive noise [36]. Also, individuals with autism spectrum disorder (ASD) who are highly sensitive to sound are the ones who suffer the most from sound pollution. They may develop panic and distress [37]. Construction areas and transport systems should be managed in a way to avoid noise pollution. Second, light pollution is the over illumination in the cities (Figure 11). Street and building lightning may disturb circadian rhythm of the city residents and result in sleep disorders, depression, and anxiety disorders [15,38]. Third, air pollution may be the most threatening stressor for city dwellers. Air quality is also the most important criteria of neuroarchitecture [4]. Exposure to air pollutants such as lead, solvents, pesticides, and some building materials can lead to serious neurological and cognitive impairments. Improper air quality can cause anxiety, depression and concentration problems in children and adults [39]. Therefore, clean air must be provided by expanding greenery in cities and improving the quality of signages and quality of roads to avoid traffic-related air pollutants [15]. Moreover, policymakers and urban planners must carefully manage all these environmental stressors to maximize mental health of city dwellers. In addition to environmental stressors, social stress caused by not being together socially is also a threat to our mental health. For this, spaces that encourage social cohesion should be created, and planning should be done to offer people places where they can improve themselves [13].

Figure 11. *Light and Noise, as Environmental Stressors, Istanbul (photo belongs to the author).*

3. FUTURE DIRECTIONS

Further neuroarchitecture findings to be obtained with the help of new technologies will provide insight in order to design better cities. Especially, mobile EEG systems to measure "stress street score" [40], and artificial intelligence applications to estimate how people have an embodied experience of the built environment seem promising [15]. Besides, neuroarchitecture may provide us with a deeper understanding of how non-typical brains such as people with ASD and dementia experience the urban life [19]. Therefore, cities should be designed in a more inclusive way. The collaboration of architects, urban planners and neuroscientists will be immensely needed in the near future.

4. CONCLUSION

All in all, attention should be paid to the design criteria suggested by neuroscience in the urban planning. According to these criteria, those living in a healthy city should be able to find their way easily. For this, it is important that the city has a mirror-symmetrical plan and wide streets with proper directional signs on them, The presence of urban areas to support social unity will increase socialization in the city. The cities located in the seaside may enable people to benefit from the calming power of water. In addition, the inclusion of other biophilic elements such as wild green spaces and pools as well as the use of plants with different scents, colors, and textures as in urban parks and agricultural areas has a great importance in city design. The squares and streets covered with creative sculptures and street arts stimulating different senses of urban dwellers should also be preferred.

The architecture of the cities has an important role in the cognitive effect of the city on people. The buildings should not be monotonous and should have an architecture that activates people's emotions with the use of different forms, colors and materials in design and facades. In addition, the buildings should be insulated in such a way that the noise of the city is not let in. The use of natural materials such as natural stone and wood in buildings and the construction of buildings with green facades and roofs should be encouraged. In summary, there are many topics in urban design to be enriched with the new discoveries in the field of neuroscience.

The cities we live in can shape our brain and behavior. Hence, designing healthy, conscious, and sustainable cities is a huge global challenge in our rapidly populated world. In this sense, the aim of the neuroarchitecture and neurourbanism disciplines are to create a positive urban experience. What is more, well-enriched cities with lots of vitality elements in it are shown to affect our brain regulation,

neuroplasticity, and behavior. Thus, designing a neuro-diverse city experience is extremely important for our physical and mental health.

Neurourbanism criteria, which are known to have an impact on people's mental health through urban studies of neuroscience, can be summarized as navigation, interaction with nature, embodied experiences and environmental factors. Cities designed by paying attention to these, should be designed to facilitate navigation, interact with nature, offer opportunities that activate our five senses (flowers of various colors and scents, enable street art performances, etc.), be far from environmental factors such as noise, air, and light pollution. Paying attention to the proposed neurourbanism criteria will lead to the formation of healthy societies with mentally healthier individuals.

REFERENCES

[1] Lampard EE. The History of Cities in the Economically Advanced Areas. Econ Dev Cult Change [Internet]. 1955 Sep 29 [cited 2022 Jun 28];3(2):81–136. Available from: https://www.journals.uchicago.edu/doi/10.1086/449680

[2] James FJ, Romine J a., Zwanzig PE. The Effects of Immigration on Urban Communities. Cityscape [Internet]. 1998 [cited 2022 Jun 28];3(3):171–92. Available from: https://www.jstor.org/stable/20868463?seq=1

[3] Meredith S. Two-thirds of global population will live in cities by 2050, UN says [Internet]. Cnbc. 2018 [cited 2022 Jun 28]. p. 1–6. Available from: https://www.cnbc.com/2018/05/17/two-thirds-of-global-population-will-live-in-cities-by-2050-un-says.html

[4] Coburn A, Vartanian O, Chatterjee A. Buildings, beauty, and the brain: A neuroscience of architectural experience. J Cogn Neurosci. 2017 Sep 1;29(9):1521–31.

[5] Tekin İ, Akpınar İ. Betonarmenin Anonimleşmesi: Türkiye'de İkinci Dünya Savaşı Sonrası Yapılı Çevrenin İnşası. Mimar Derg [Internet]. 2014 [cited 2022 Jun 27];377. Available from: http://www.mimarlikdergisi.com/index.cfm?sayfa=mimarlik&DergiSayi=391&RecID=3404

[6] de Botton A. Why is the Modern World So Ugly? [Internet]. The School of Life. 2021 [cited 2022 Jun 28]. Available from: https://www.theschooloflife.com/article/why-is-the-modern-world-so-ugly/?fbclid=IwAR2O-FvbBlJvqv_oFvZd4Xny8oDnpsc9xT43noy2e6jwcCreiyermrSGoh4

[7] Peen J, Schoevers RA, Beekman AT, Dekker J. The current status of urban-rural differences in psychiatric disorders [Internet]. Vol. 121, Acta Psychiatrica Scandinavica. John Wiley & Sons, Ltd; 2010 [cited 2022 Jun 28]. p. 84–93. Available from: https://onlinelibrary.wiley.com/doi/full/10.1111/j.1600-0447.2009.01438.x

[8] Chen Z, Liu M, Zhang S, Xiong Z, Zhong X, Yang D, et al. Urban index and lifestyle risk factors for cardiovascular diseases in China: A cross-sectional study. Sci Prog. 2021;104(1).

[9] Pearce MT, Zaidel DW, Vartanian O, Skov M, Leder H, Chatterjee A, et al. Neuroaesthetics: The Cognitive Neuroscience of Aesthetic Experience. Perspect Psychol Sci. 2016 Mar 1;11(2):265–79.

[10] Eberhard JP. Applying Neuroscience to Architecture. Vol. 62, Neuron. Cell Press; 2009. p. 753–6.

[11] Dance A. The brain within buildings. Proc Natl Acad Sci U S A [Internet]. 2017 Jan 31 [cited 2022 Jun 28];114(5):785–7. Available from: www.pnas.org/cgi/doi/10.1073/pnas.1620658114

[12] Adli M, Berger M, Brakemeier EL, Engel L, Fingerhut J, Gomez-Carrillo A, et al. Neurourbanism: towards a new discipline. The Lancet Psychiatry. 2017 Mar 1;4(3):183–5.

[13] Berg K. Sağlıklı kentler: nero şehircilik araştırma dalının hedefi [Internet]. 2020 [cited 2022 Jun 28]. Available from: https://www.deutschland.de/tr/topic/cevre/saglikli-kentler-nero-sehircilik-arastirma-dalinin-hedefi

[14] Ritchie I. Designing with the Mind in Mind. John Wiley & Sons, Incorporated; 2021.

[15] Camargo A, Artus J, Spiers HJ. Neuroscience:A Playbook for Placemakers. Connect Places Catapult [Internet]. 2021 [cited 2022 Jun 28]; Available from: https://neuro-architectology.com/neuroscience-

a-playbook-for-placemakers/

[16] Rooney KK, Condia RJ, Loschky LC. Focal and ambient processing of built environments: Intellectual and atmospheric experiences of architecture. Front Psychol. 2017 Mar 16;8(MAR):326.

[17] CR U. Diagram showing the lobes of the brain [Internet]. Wikimedia Commons. [cited 2022 Jun 28]. Available from: https://commons.wikimedia.org/wiki/File:Diagram_showing_the_lobes_of_the_brain_CRUK_308.svg

[18] Jeffery K. Urban Architecture: A Cognitive Neuroscience Perspective. Des J. 2019 Nov 2;22(6):853–72.

[19] Higuera-Trujillo JL, Llinares C, Macagno E. The cognitive-emotional design and study of architectural space: A scoping review of neuroarchitecture and its precursor approaches [Internet]. Vol. 21, Sensors. Multidisciplinary Digital Publishing Institute; 2021 [cited 2022 Jun 28]. p. 1–47. Available from: https://www.mdpi.com/1424-8220/21/6/2193/htm

[20] de Paiva A, Jedon R. Short- and long-term effects of architecture on the brain: Toward theoretical formalization. Front Archit Res. 2019 Dec 1;8(4):564–71.

[21] Kaplan R, Kaplan S. The experience of nature: a psychological perspective. Exp Nat a Psychol Perspect. 1989;

[22] Mehaffy M. Biophilic Design: The Theory, Science, and Practice of Bringing Buildings to Life. Proc Inst Civ Eng - Urban Des Plan [Internet]. 2012 [cited 2022 Jun 28];165(3):193–193. Available from: https://www.wiley.com/en-us/Biophilic+Design%3A+The+Theory%2C+Science+and+Practice+of+Bringing+Buildings+to+Life-p-9780470163344

[23] Yan W. Neuroscience Informs Design, Now What? Towards an Awe-inspiring Spatial Design. Conscious Cities Anthol. 2019 Oct 7;2019(1).

[24] Olszewska-Guizzo A. Neuroscience-Based Urban Design for Mentally Healthy Cities. In: Urban Health and Wellbeing Programme Policy. 2021. p. 13–6.

[25] Myers Z. Wildness and wellbeing: Nature, neuroscience, and urban design. Wildness and Wellbeing: Nature, Neuroscience, and Urban Design. 2019. 1–153 p.

[26] Berg K. Şehir planlaması ve iklim değişikliği | Şehirleri serinleştirmeye yönelik fikirler [Internet]. 2020 [cited 2022 Jun 28]. Available from: https://www.deutschland.de/tr/topic/cevre/sehir-planlamasi-ve-iklim-degisikligi-sehirleri-serinlestirmeye-yonelik-fikirler

[27] Anderson AP, Mayer MD, Fellows AM, Cowan DR, Hegel MT, Buckey JC. Relaxation with immersive natural scenes presented using virtual reality. Aerosp Med Hum Perform. 2017 Jun 1;88(6):520–6.

[28] LeDoux JE. Cognitive—emotional interactions in the brain. Cogn Emot [Internet]. 1989 Oct 1 [cited 2022 Jun 28];3(4):267–89. Available from: https://www.tandfonline.com/doi/abs/10.1080/02699938908412709

[29] Higuera-Trujillo JL, Llinares C, Macagno E. The cognitive-emotional design and study of

architectural space: A scoping review of neuroarchitecture and its precursor approaches [Internet]. Vol. 21, Sensors. Sensors (Basel); 2021 [cited 2021 Jul 28]. p. 1–47. Available from: https://pubmed.ncbi.nlm.nih.gov/33801037/

[30] Evans JC (Jon C (Jon C. Imminence and immanence : embodied meaning in architectural experience. Art [Internet]. 1992 [cited 2022 Jun 29]; Available from: https://www.semanticscholar.org/paper/Imminence-and-immanence-%3A-embodied-meaning-in-Evans/21b5876a6f06977b403f16ec7e4e7ef0dd021b42

[31] Urban Food Street. Urban Food Street [Internet]. 2015 [cited 2022 Jun 29]. Available from: http://www.urbanfoodstreet.com/

[32] Ellard C. Neuroscience, Wellbeing, and Urban Design: Our Universal Attraction to Vitality. Psychol Res Urban Soc. 2020 Jun 26;3(1):6.

[33] Kostrzewska M. Activating Public Space: How to Promote Physical Activity in Urban Environment. In: IOP Conference Series: Materials Science and Engineering [Internet]. IOP Publishing; 2017 [cited 2022 Jun 29]. p. 052074. Available from: https://iopscience.iop.org/article/10.1088/1757-899X/245/5/052074

[34] Schoentgen B, Gagliardi G, Défontaines B. Environmental and Cognitive Enrichment in Childhood as Protective Factors in the Adult and Aging Brain. Front Psychol [Internet]. 2020 Jul 21 [cited 2022 Jun 29];11. Available from: /pmc/articles/PMC7385286/

[35] Errett J, Bowden EE, Choiniere M, Wang LM. Effects of noise on productivity: Does performance decrease over time? In: AEI 2006: Building Integration Solutions - Proceedings of the 2006 Architectural Engineering National Conference [Internet]. 2006 [cited 2022 Jun 29]. p. 18. Available from: https://digitalcommons.unl.edu/archengfacpub/13

[36] Martin PR, Reece J, Forsyth M. Noise as a trigger for headaches: Relationship between exposure and sensitivity. Headache [Internet]. 2006 Jun 1 [cited 2022 Jun 29];46(6):962–72. Available from: https://onlinelibrary.wiley.com/doi/full/10.1111/j.1526-4610.2006.00468.x

[37] Kanakri SM, Shepley M, Varni JW, Tassinary LG. Noise and autism spectrum disorder in children: An exploratory survey. Res Dev Disabil. 2017 Apr 1;63:85–94.

[38] Chepesiuk R. Missing the dark: Health effects of light pollution. Environ Health Perspect. 2009;117(1).

[39] Kampa M, Castanas E. Human health effects of air pollution. Vol. 151, Environmental Pollution. Elsevier; 2008. p. 362–7.

[40] Jebelli H, Khalili MM, Lee S. Mobile EEG-based Workers' Stress Recognition by Applying Deep Neural Network. In: Advances in Informatics and Computing in Civil and Construction Engineering [Internet]. 2018 [cited 2022 Jun 29]. Available from: https://www.researchgate.net/publication/327043710_Mobile_EEG-based_Workers'_Stress_Recognition_by_Applying_Deep_Neural_Network

[41] McCay L, Bremer I, Endale T, Jannati M, Yi J. Urban Design and Mental Health. In Springer, Singapore; 2017 [cited 2022 Jun 27]. p. 421–44. Available from: https://link.springer.com/referenceworkentry/10.1007/978-981-10-2327-9_12

[42] Zarif H, Nicolas S, Petit-Paitel A, Chabry J, Guyon A. How Does an Enriched Environment Impact Hippocampus Brain Plasticity? In: The Hippocampus - Plasticity and Functions. InTech; 2018.