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Research Article

Short- and long-term effects of architecture on the brain: Toward theoretical formalization

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Abstract The physical environment affects people's behavior and wellbeing. Some effects can be easily noticed through observation, whereas others require an in-depth study to be understood and measured. Although many alterations can be positive, some can also negatively influence wellbeing, decision-making, and mental and physical health. Some of these effects are not easily associated with physical space. Thus, people may be unaware of the real triggers for changes in behavior, mood, and wellbeing. Although many studies have been performed on environmental psychology, detailed research to understand the impacts of architecture on the brain using neuroscience is limited. Some difficulties experienced by researchers in this field are on the isolation of each stimulus to understand its effects individually and measurement of brain changes in people interacting with the environment because some brain scans, such as fMRI, require people to be inside the machine. Nonetheless, the several ways a space can impact its users should be discussed to understand how architecture influences individuals and to help architects and urban planners in designing efficient and healthy spaces. This study aims to describe and analyze the results of previous research works and propose a way of organizing them to facilitate further investigation on this field.

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1. Introduction

"Every man can, if he so desires, become the sculptor of his own brain" (Ramón y Cajal, 2004)

Cities and buildings are places where people spend most of their lives. Individuals grow up, study, develop, work, meet old and new friends, start forming families, raise their children, and even die in places built by men. These places help shape their lives. Behaviors, choices, emotions, and physical and mental health can be influenced by spaces. However, whether architects, as well as psychologists, psychiatrists, and neuroscientists, have considered all the short- and long-term impacts that spaces can have on people is still questionable.

Architects and environmental psychologists have long been aware of the importance of understanding how spaces affect individuals. Through empirical research, they were able to measure changes in behavior. "It turns out people have multiple subconscious tendencies and behaviors that govern their responses to built environments" (Rock, 2009). Recent findings, technologies, and research methods in the field of neuroscience can help understand physiological transformations in the brain and body that trigger changes in behavior. Such physiological changes vary in accordance with when and for how long individuals are exposed to the same stimuli.

Homes, schools, and cities are the main places where people grow up. Childhood memories are some of the strongest ones for most people: memories with their families at home, the first discoveries and friendships at school, and the first explorations and trips around the city. However, these moments are more than potential fond memories. During childhood, critical periods of development take place in several areas in the brain. Childhood is when individuals are most vulnerable to several kinds of external stimuli, such as the physical environment.

However, these influences do not stop in adulthood. As Fred Gage affirmed: "Changes in the environment change the brain, and therefore they change our behavior. In planning the environments in which we live, architectural design changes our brain and our behavior" (Gage, 2003). Thus, spaces continue to influence and change us during our entire lives.

This information is not entirely new for psychologists and architects. Environmental psychologists have been studying the influences that spaces have on behavior since the 20th century. However, their findings were based on empirical studies. They observed how individuals differently behave in distinctive environments using evidence-based design. However, such studies cannot measure brain reactions as it is possible today due to the technological limitations at that time. Therefore, they cannot handle the entire complexity of the relation between neuroscience and architecture.

In addition to empirical studies, architects can directly research the users of buildings and cities and ask for their opinions and feelings about spaces. Nonetheless, the ability to consciously process information is less than 1% of the ability of unconscious processing (Eagleman, 2011). Hence, most stimuli will affect individuals on a subconscious level. Although people may be affected by stimuli, they will not be necessarily aware of the effect.

Furthermore, these data (the empirical observation of outsiders or the conscious opinion of users) are only the results of a reaction to stimuli, not the actual reaction. The difference is that now, with neuroarchitecture (the interdisciplinary field of neuroscience applied to architecture), researchers and architects can uncover the causes of changes in behavior and opinion. They can now measure physical changes in the brain and body that happen as a result of the interaction between the brain and built space. These physiological changes, such as the activation of specific brain areas and changes in hormone levels and skin conductance, can help further understand the effects of the environment on people. These impacts can be divided in accordance with the time of exposure that is necessary for the change to happen and the duration of the effect (ephemeral effects or enduring ones).

The physical environment does not always affect people equally. Furthermore, other important variables, such as personal features (genetics and individual memories and experience) and the social environment, affect how people can be influenced. Therefore, although the physical space is not the only variable in this equation, it plays a key role on the wellbeing, behavior, emotions, and decision-making.

2. Architecture—individual relation

"We shape our buildings; thereafter, they shape us." (Churchil, 1943)

Individuals are in constant active interaction with the many environments surrounding them. A warm room can cause people to sweat, feel uncomfortable, and unable to concentrate. A dark room can make people feel afraid, stay alert, and unable to relax. A classroom well lightened with natural light can help students be attentive to the class. The environment always affects the individuals who occupy it in some level. This interaction can be named as an architecture—individual relation.

Spaces can change people (architecture—individual), and people can change spaces (individual—architecture). Therefore, this relation is a two-way path. Nevertheless, the direction of the architecture—individual relation is yet to be explored by researchers.

This relation can be compared, in some way, with the cell—environment chemical relation. Cells are constantly changing and adapting to the environment they are located in (Berg et al., 2002). From an evolutionary perspective, the same happens to all living beings. "The evolutionary success of an organism is a testament to its inherent capacity to keep pace with environmental conditions that change over short and long periods" (Brooks et al. 2010).

The way people adapt to the physical environment can vary in several factors: genetics, cultural and personal memories and experiences, and the frequency and duration of exposure to the environment (physical and social). In addition, the brain actively interacts with the physical environment: it is always engaged in some sort of activity, such as work, rest, buy, learn, recover, remember, and create. All these core variables affect how architecture can influence individuals. As such, studying the impacts of the built space on people is difficult because many variables are involved and some of them are difficult to measure.

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Among all the pointed variables, time (frequency and duration) is the easiest one to control and measure. Therefore, we chose time to differentiate the groups of spaces and effects: spaces that are occupied for a short period of time (short-term exposure) or spaces that are occupied for a long period of time (long-term exposure) and effects that have a short or a long duration.

Hence, we propose to divide the changes in accordance with the time/frequency of occupation of a space (short- or long-term exposure) and on the permanence of the effect (short- or long-term effect). This division leads to four possible combinations: (i) short-term exposure, short-term effect (quick alteration of the existing machinery to operate optimally in a new environmental condition); (ii) long-term exposure, long-term effect (slow reorganization of the existing machinery to adapt to the environment); (iii) short-term exposure, long-term effect (a mix of the two previous items); and (iv) long-term exposure, short-term effect. The fourth possible combination, that is, long-term exposure, short-term effect, was not considered in this article because long-term exposure includes duration (continuous exposure) and frequency (discontinuous exposure) that repeatedly occurs often and for a long time. Therefore, a short-term effect will probably arise on the first few hours of occupation, fitting in the short-term exposure, short-term effect (i) category.

The word "exposure" was chosen instead of "occupation" or "interaction" because the physical space is considered a stimulus to which individuals can be exposed to. In this case, we consider that exposure is a general term that can include occupation or interaction when it is the case. This exposure can be active (e.g., people go to schools to learn, hospitals to recover, restaurants to eat, and home to inhabit) or passive (e.g., people do not necessarily interact with the color of the walls or with the view of the window). When individuals are exposed (actively or passively) to a stimulus or a set of stimuli, they can be affected by it or them. Therefore, the word "effect" was chosen to classify the different effects in accordance with its permanence because the effects can be ephemeral or enduring.

Short-term exposure, short-term effect is an immediate reaction (a short-term reaction) that is not enduring. It mostly happens to help individuals adapt while they are still in the space that triggered the change. However, such optimization changes can still last a few hours after the individual leaves that space. These alterations include changes in emotions, working memory, hormone levels, heart rate, skin conductance, blood pressure, body temperature, and muscle tension.

One of the most common short-term optimization happens when a threat is identified and the brain and body prepare to enter on a flight or fight state. A person who has vertigo, for instance, will immediately start feeling dizzy near a window on the top of a skyscraper because they are perceived as a threat to the body integrity. The heart rate, muscle tension, and body temperature of the person will increase. At the same time, the person will feel scared and afraid. Even after going back to the ground floor, they might still feel a little uncomfortable for a while until recovering completely.

Meanwhile, long-term exposure, long-term effect requires repeated stimulation prolonged over time to happen. For instance, spending a day at home can be helpful to lower stress levels and relax (short-term effect). However, for older people who have stopped working and rarely leave the house, spending a day at home can cause their brain to change plastically, thereby losing its efficiency and promptness in time (long-term effect). Usually, long-term effects not only take more time to happen; they also need more time to be reverted. Sometimes, they may not be reverted at all, especially if the stimuli that induced them are still present.

Other examples are spaces that require complex navigation, such as hospitals or cities. In most cases, a few visits will be necessary for people to circulate without getting lost (repeated stimulation). "Repetition plays a dual role in memory: (i) the maintenance of information in primary or short-term memory, and (ii) the transfer of information into a secondary or long-term store. This conception leads to the prediction that the amount of time that an item is rehearsed in short-term memory should be directly related to its recall probability from long-term memory" (Chabot et al., 1976).

The short-term exposure, long-term effect consists of a reaction that happens quickly. However, the effect is so intense that it does not require repetition to be engraved in the brain. When a stimulus generates emotions that are strong (short-term exposure, short-term effect), long-term memories can be usually formed without the necessity of repetition. Therefore, a short exposure to the stimulus can lead to long-term changes in the brain. Traumatic experiences can be a good example to illustrate the short-term exposure, long-term effect. Usually, the trigger to the trauma happens quickly, such as car accidents, but the trauma persists for a long time.

An architectural example can be remarkable places that require just one visit to be recorded by the brain and never be forgotten. One visit to Gaudi's Sacred Family Church, for instance, is enough to create an unforgettable memory. This visit is an example of a short-term contact generating long-term memories. Conversely, other spaces, such as regular churches, may not be so remarkable and will need more than one visit to be properly engraved on memory.

Therefore, this study proposes that the effects of architecture will not only depend on the physical features of the space. Time and frequency of occupation have key roles on how space can impact individuals, and they are easy to measure and control. Both are strategic elements to help understand the architecture—individual relation. A short occupation can result in a more immediate — but less permanent in most cases — adaptation. Conversely, a long and frequent occupation can result in a complex and structural alteration that lasts longer.

3. Short-term exposure, short-term effects of architecture in the brain

"Organisms respond to short-term environmental changes by reversibly adjusting their physiology to maximize resource utilization while maintaining structural and genetic integrity by repairing and minimizing damage to cellular infrastructure thereby balancing innovation with robustness" (Brooks et al. 2010)

Short-term exposure, short-term effects are mostly those that happen after an interaction with the space, which lasts from a few seconds to one day. Hence, as soon as a person enters a room or building, the person can be affected by it. These effects can vary from slight changes in the direction of an individual's walk (Leonards et al., 2015); increased or decreased working memory (Radvansky et al., 2011); changes in muscle tension, heart rate, and blood pressure; to changes in emotions and mental states. Short-term effects can be immediate (a quick response or reflex) or they can require a long time of occupation and complex interaction with the space to happen.

Immediate impacts happen as a fast reaction to the architectural stimuli. They do not necessarily require any physical interaction with the environment. Just perceiving it through the senses (especially sight, hearing, smell, and touch) is enough to evoke such immediate impacts. For instance, information about the space is brought by the senses to the brain directly upon entering a building or facing a street. In turn, the brain adapts itself and the body to the new environment. Moreover, the pupils dilate and individuals become attentive to notice any obstacles that may be on their way as soon as they enter a dark unknown room.

Meanwhile, short-term exposure, short-term effects arise as a result of a complex interaction with architecture. It also requires more than just a moment of exposure to the architectural stimulus. A person who is writing a creative short paper may go to a co-work space for a few hours to perform the task. Features from the chosen space (such as light, noise, layout, temperature, colors, and shapes) can cause physiological reactions that may help or hinder a person to be in the best mental state to fulfil a task.

Fig. 2 illustrates the levels of changes that happen in individuals in order to regulate the body to the environment, from the most primitive ones, such as metabolic regulation, basic reflexes, and immune responses, to the most elaborate ones, such as emotions and feelings (Damásio, 2003). According to the neuroscientist António Damásio, these changes are responses to enhance the chances of survival in the environment (physical and social).

The levels of perception of such changes vary on how elaborate the response is. Individuals are less consciously aware of more primitive regulations (bottom of the tree)

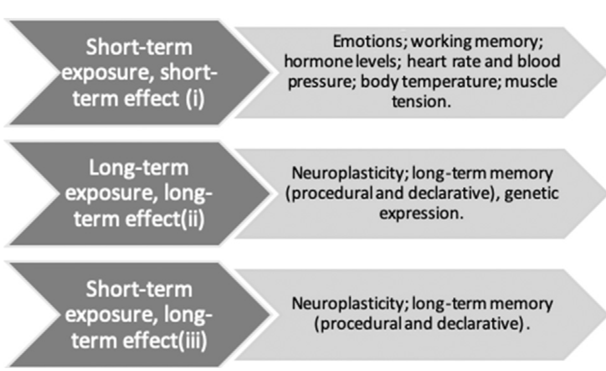

Fig. 1 Proposed kinds of biological regulation to adapt individuals to the environment (Andréa de Paiva).

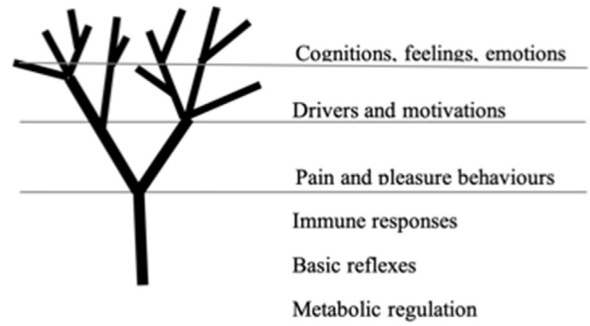

Fig. 2 Levels of automated homeostatic regulation, from simple to complex (Damásio, 2003).

than they are of the more elaborate ones (top of the tree). For instance, some qualities of the physical environment can impair the immune system, but most people will only be aware of the impairments after showing some symptoms of illness. Biophilia, the field that studies how nature can influence the brain and body, is a good example. It reveals that the closer people are to nature, the better immune response they get (Salingaros, 2015). A short-term exposure, short-term effect in this case can be the fact that just by viewing a natural sight for a few minutes can help lower stress levels, blood pressure, and muscle tension. A long-term exposure, long-term effect can be the improvement of the immune system.

Natural and artificial light are great examples of the direct impact of physical environment on metabolic regulation (bottom of the tree) without conscious perception from the individual. Through light, the brain synchronizes a great part of its operation with the external world (the circadian rhythm) to cover the 24-h period in which the activities of the biological cycle happen. Light also regulates physiological and psychological rhythms, directly impacting wakefulness and sleep, hormone secretion, cellular function, and genetic expression.

The photoreceptors on the retina, which work even with the eyes shut, respond to artificial and natural light. Hence, the use of the electric lamp and electronic devices allows people to extend the day, deregulating the circadian rhythm. Such deregulation in the short term can influence many brain systems responsible for mood control, such as limbic system and hypothalamic–pituitary axis, and the secretion of glucocorticoids (e.g., cortisol). As a result, the deregulation can cause insomnia and other sleep disorders, privation of mood control, trends of (winter) depression, loss of concentration, enhanced stress levels, and impaired immune system in the long term (Bedrosian and Nelson, 2017).

In this case, instead of optimizing the machinery, the biological regulation to adapt to the environment can be injuring it. Furthermore, the privation of mood control and enhanced stress levels can affect behavior and decision-making. Hence, the physical environment, through biological regulation, can negatively influence behavior.

Going to the top of the tree, one of the main factors that can influence mental states is emotions. According to António Damasio (1994), emotions are generated in the brain and experienced by the whole body. They are innate

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reactions of the brain that are expressed through facial expressions, body language, and attitudes (Ekman, 2003). They affect the way people feel consciously or unconsciously (Damásio, 2003), thereby triggering changes in behavior and wellbeing. Therefore, the body is an important element in the brain—environment relation.

Emotions are also essential in decision-making and behavior. People with damages in brain areas responsible for processing emotions have experienced changes in their personalities and behavior (Damasio, 1994). Consequently, changes in emotional states can also change behavior.

According to Paul Ekman, at least six universal emotions exist: fear, disgust, anger, happiness, sadness, and surprise. These emotions are innate to all human beings, as Ekman discovered in his studies with tribes from Papua New Guinea (Ekman, 2003). Several different factors can evoke these emotions at some level. Physical space is also a factor. Cultural symbols and physical elements, such as ceiling height, proportions, textures, lighting, shapes, colors, temperatures, smells, and even sounds, can be used for that. Gothic churches mostly have such high ceilings, stained glass windows, and an altar. Throne rooms are often decorated with red elements, and the throne is located in an altar due to similar reasons. Both examples show a deep intention behind architecture and a strategic use of space to induce behavior and connection by evoking different emotions.

Another feature regarding the short-term effects of emotions is that they also influence the way people perceive the world. Individuals see the world through a filter created by the emotion they experience at the moment (Damásio, 2003). A person feeling fear may find a dark room scarier than when feeling happy. A beautiful landscape view will seem more interesting for people that are in love than for those who are angry. Thus, when the design of a building changes one's mental state and emotion, this person may perceive space differently. Moreover, the person may change his/her perception of the situations he/she experiences in such space. Consequently, when in a throne room, for instance, individuals may perceive the queen or king as even more powerful.

Finally, emotions, as well as attention, memory formation, and its recall, are essential in the decision-making and perception of the environment. "Emotional stimuli appear to consume more attentional resources than non-emotional stimuli. Moreover, attentional and motivational components of emotion have been linked to heightened learning and memory. Hence, emotional experiences/stimuli appear to be remembered vividly and accurately, with great resilience over time" (Tyng et al. 2017).

Therefore, an architecture that evokes intense emotional responses may help individuals to be attentive to the present moment and the space itself. It may also increase memory formation and its recollection. As a result, it can facilitate wayfinding and orientation. Furthermore, a short-term exposure, long-term effect can be induced, as mentioned in the Sacred Family Church visit example, depending on the intensity of emotional response.

To sum up, several short-term effects of architecture occur on the brain and behavior. They can vary from changes in primitive biological regulations, such as immune system or metabolic regulation, to complex ones, such as emotions. Furthermore, they can change the perception on spaces and situations. These examples are some of the short-term exposure, short-term effect, as shown in Fig. 1. On the one hand, short-term exposure, long-term effects happen to help the individual adapt to the environment. On the other hand, they are related to the way intense emotional arousal can impact memory and learning. Therefore, a quick reaction can, in such cases, endure on the long term.

4. Long-term exposure, long-term effects of architecture in the brain

Long-term exposure, long-term effect are those that can last for a long time even when the exposure to the environment is over. Usually, they need prolonged and repeated exposition to a similar stimuli to happen (except in the short-term exposition, long-term effect, as already mentioned): a person's home, the workplace where the person has worked for many years, or the person's every day's walk to work through the city. These examples are spaces that can act as continuous stimuli for a long time. The brain is adaptable and can change in terms of how it is or is not stimulated. Thus, spaces that are visited repeatedly for a long time can help induce changes in the brain.

The notion that the environment can cause long-term changes in the brain, as first formulated by Santiago Ramon y Cajal, is closely connected to the findings about brain plasticity (Mora et al. 2007). Studies in neuroscience found out that the brain, specifically its neural circuits and neurons, has a capacity for structural and functional changes (Eberhard, 2009; Kramer et al., 2004).

Although the focus of this study is the adult brain and its changes, the importance of spaces that are occupied by children and their long-term effects in the brain should also be studied. As already mentioned, several critical periods of the development of specific abilities occur during childhood. The spaces children attend to often and for a long time can have crucial impacts on brain development. Spaces, from prenatal nurseries to homes, neighborhoods, to schools, can generate impacts in the brain that last for a lifetime (Van Praag et al., 2000).

Studies on rats caged in a so-called enriched environment confirmed that brain plasticity in adulthood is also induced by physical space (Van Praag et al., 2000). Enriched environments are spaces that have several stimuli (physical and social). In this study, the animals were not only in large social groups and with opportunities for exercise (such as running wheels), but they were also exposed to cognitive stimulation using various objects and features in the environment (Baroncelli et al., 2010; Tost et al., 2015). These properties were continuously changed, thereby offering chances for exploratory behavior and stimulating the attention and curiosity of the animals.

Animals living in the enriched environment presented changes in brain weight, size, and thickness and better results in learning (spatial memory tasks). Furthermore, in some cases, they presented rehabilitation from a few impairments and deficits associated with brain development (Rosenzweig and Bennett, 1996). Hence, neuroplasticity is directly related to spatial features.

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Two kinds of neuroplasticity exist: neurogenesis (the production of new neurons) and rewiring (changes in the connections between existing neurons). Although several brain areas are affected by neuroplasticity (the hippocampus, cortex, and amygdala), the hippocampus is the only known area where neurogenesis happens (Rosenzweig and Bennett, 1996). It is a brain structure that plays a major role in long-term memory processes and spatial navigation. Therefore, when stimulated through enriched spaces, individuals with long-term exposure can improve memory, learning, and spatial navigation abilities (O'Keefe and Dostrovsky, 1971; Van Praag et al., 2000).

In contrast to enriched environment, scientists have also studied the changes in the brain of animals caged in impoverished spaces. These spaces were the opposite to the enriched ones. They had less social and spatial stimuli. As a result, scientists noticed that the brains of rats caged in impoverished spaces had reduced weight, showing divergent results than those in the enriched spaces (Mohammed et al., 2002). This outcome showed that enrichment is important to help improve brain plasticity and avoid its impairment.

Architects who design schools and care centers for the elderly and hospitals must consider the importance of enriched environments and the impacts of an impoverished one. Naturally, not every room in a school or hospital has to be enriched. The buildings must be planed as a whole by linking together spaces with different features. A surgery room has to be simple to be practical and help doctors focus and concentrate. However, an enriched break room for doctors and nurses and internal gardens for patients and their families in the hospital must also be built.

Although enriched environments are important to stimulate brain plasticity, the crucial difference between enrichment and chaos must be pointed out. Enriched environments have several stimuli, but they follow a pattern. In nature, for instance, patterns of shapes, colors, proportions, sounds, and smells exist. In huge cities, such as Hong Kong and New York, patterns are a mix of everything: outdoors and lights, skyscrapers that have no proportion to the human scale, traffic jams, busy streets, horns, and construction noises, among others. These examples are chaotic environments, which have excessive information without necessarily any pattern.

Chaotic environments, unlike enriched ones, can cause negative long-term changes in the brain and health. People living in cities generally have more mental health problems than those living in rural areas (Peen et al., 2010). Likewise, people growing up in urban environments are significantly more prone to psychotic disorders, namely, schizophrenia (Krabbendam and Os, 2005). The more a person is exposed during her childhood or adulthood to urban environment, the greater the risk of developing psychotic disorders (March et al., 2008).

Recent studies have shown that a possible explanation for these numbers lies not only in brain plasticity but also in gene—environment interaction. Urbanized areas can negatively influence individuals who are genetically susceptible to psychotic disorders. In turn, the influence leads to a high incidence of such disorders in urban environment compared with rural areas (Weiser et al., 2007). A possible reason for such results is that numerous stress factors, such as population density and crowding, social isolation, air pollution, noise, life style, and spatial configuration, are common in huge cities. Exposure to such environmental stress factors for long periods of time can have severe effects for the susceptible individuals. For instance, hearing loss is the most obvious effect of excessive noise. However, the World Health Organization outlines other detrimental effects of noise, such as disruption of the circadian rhythms during sleep, reduction of sense of control over the environment, and impaired cognitive functions (Goldhagen, 2017).

Long-term effects of architecture in the human brain can also happen indirectly through its impacts on human behavior. A beneficial factor for human physical and mental health and brain plasticity is physical exercise (Mora et al., 2007). Physical exercise not only helps to keep the body strong and health, but it also stimulates the production of brain-derived neurotrophic factor, which is a substance that helps in neuronal growth, maturation, and maintenance. It is also related to cognitive reserve, which is the brain's ability to resist damage while maintaining a good performance (Cheng, 2016). Architectural design can also increase physical activity by stimulating circulation throughout the space. The presence of sidewalks, attractive streets, enjoyable scenery, and hills, for instance, can encourage walking (Jackson, 2003).

Circulation throughout the space has also another beneficial aspect: social interaction (Goldhagen, 2017). Social interaction has various effects on mental and physical health because both characteristics are contrarily linked with several diseases, from colds to heart attacks, depression, strokes, and cancer (Jackson, 2003). Therefore, environments designed to support human activities and social interaction can help to avoid or attenuate several problems.

Another important factor influenced by architectural designs that greatly affects the brain is perceived stress. In the context of mental health, chronic stress is associated with depression, with plastic alterations of the amygdala, hippocampus, and cortex (McEwen, 2013).

Spaces can increase perceived stress levels in many ways (short-term exposure, short-term effect). However, when individuals are often exposed to such spaces, stress becomes a long-term exposure, long-term effect. Simple factors, such as toilet location and accessibility, spaces for privacy, and good signalization to help navigation, are important elements that can have a great influence over perceived stress levels.

All of the findings on enriched environment and brain plasticity and gene—environment interaction, among others, show how much the architectural design of built spaces can shape the brain and behavior. Poor, monotonous, and sterile designs can lead to several consequences ranging from boredom to a lack of physical activity and social interaction (short-term exposure, short-term effect). These consequences, in time, can lead to mood and anxiety disorders and worsening of cognitive functions (long-term exposure, long-term effect). By contrast, architectural environments that offer cognitive, social, and physical stimulation can help prevent many physical illnesses and mental diseases, avoid stress, and enhance learning and memory processes.

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5. Conclusion

People are in constant interaction with the spaces surrounding them. The brain and body are permanently adapting to the external stimuli from the environment to improve chances of survival.

In this article, we discuss how built spaces can affect the brain by focusing on the short- and long-term effects. Although architects and environmental psychologists have long been discussing this subject, recent findings in neuroscience has brought new insights into such discussions. With neuroimaging examinations, the external reactions people have in response to spaces, such as changes in behavior, and the internal ones, which result in behavioral changes, can be readily analyzed.

One of the greatest challenges in studying this field is that the effects of architecture depend not only on the physical features of the space. Several other factors can influence how a built environment affects individuals: the time and frequency of use, the way individuals interact with the environment (the activities they will do on each space), culture and personal experience, and the social environment. Furthermore, spaces are rich in information, and each feature is hard to isolate from one another to understand its impacts individually.

However, we propose to consider two main variables to systematize the effects and help future research: time/frequency of occupation and duration of the effect. Accordingly, we presented three kinds of combination: short-term exposure, short-term effects; long-term exposure, long-term effects; and short-term exposure, long-term effects. A short-term occupation can result in a more immediate — but less permanent in most cases — adaptation. A longer and more frequent occupation can result in more complex and enduring alterations. Finally, some specific conditions that lead to extreme levels of emotional arousal can generate permanent effects, even after a short time of occupation.

As several studies have shown, the brain adapts to the environment to enhance survival chances. However, not every adaptation is positive. As such, apart from all the challenges, architects, psychologists, and neuroscientists must join forces on this investigation. Neuroarchitecture studies can also help to improve the design of buildings and cities and improve health and wellbeing on the short and long term.

Conflict of interest

There is no conflict of interest.

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