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Exploring the architectural design powers with the aid of neuroscience (little architect's adventure)

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ABSTRACT

Neuroscience, with the aid of new technologies, is opening exciting doors to the essence of brain; showing that the built environment plays an important role in the physical and emotional health of its users, widening up for children to affect their learning and development processes. This research sought to give architects an exploration of the architectural design' latent powers, through an authentic experiment, carried out to assess the effect the different design decisions have on children's physiological and psychological states, hence on their brain's development.

Correspondingly, the core purpose of smart cities is ensuring the creation of inclusive environments that guarantee the individuals wellbeing. The research achieved progress by reflecting on a children sample examining different architectural alternatives through virtual reality, while their physiological and emotional states were monitored. This research shed light on the potentials found in the involvement of the physiological, psychological measures in assisting the architectural design.

1. Introduction

Neuroarchitecture is an interdisciplinary emerging field, resulting from the integration of neurology, psychology, and architecture; studying effective, sensitive, recognitive and affective reactions to environmental stimulus. This recent alignment of the 3 fields has recast our comprehension of how the architectural design influences people's states of mind [3].

The purpose of this interdisciplinary approach is to encourage the creation of environments that would contribute to peoples' flourishing in terms of behaviour, health, and well-being.

In fact, neuroscientists can help architects understand scientifically what have historically been intuitive, through new neuroscience's discoveries that are helping us bridge the gap that exists between the physical built environment and the human perception and behaviour. According to Paiva, it is proven that the surrounding built environment could have a direct impact on the way the unconscious mind works, and on a conscious level, great portion of such impact will go unnoticed [4]. However, the 2 brain systems: conscious and unconscious, are responsible together of the way we perceive our surrounding environment, and therefore how we behave and react with it. Furthermore, recent discoveries in the complexities of the brain and neural systems emphasize the innately multi-sensory nature of our architectural experiences.

The aim of this research was to examine the neuroscientific research' assistance in the exploration of the architectural design impacts on its users; through the application of the neuroarchitecture findings, in particular, on children's perception of their built environment. As a result of the fact saying that children are the most susceptible individuals to the external stimuli [5], such as architectural environments, due to their absorbing mind; which means that the critical periods of their brain development, and their absorption to knowledge, happen in their early childhood [6]. Moreover, according to Dunn (2012), it is proven that the effects of the environmental elements have a wider impact on children starting from 3 years, due to the expansion of their geographical range [7].

Also, the learning spaces have been chosen as a specified building type for application, leaning on the discoveries that prove that the architectural elements can make particular brain areas more receptive to learning, and affect how information are retained.

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2. Methods

The experiment is built on two components: an interactive individual activity and a collaborative workshop. Initially, the first component starts with a virtual reality experience, letting children experience multiple scenarios of their actual daily learning environment, where the architectural elements vary in every alternative; simultaneously, this activity is done in parallel with the information extraction phase, to explore with the available possible tools the accurate effects of those architectural varying elements on children, following the plan mentioned below:

- With the aid of a smart watch, worn by the child during his virtual reality experience of the multiple alternatives, the heart rate is measured as a main physiological variable, affected by the state of mind, which in turn is affected by the built environment.
- With the aid of a thoroughly designed assessment toolkit, that simplify the human universal emotions in common expressive stickers, the changes in emotions are measured; in the form of a feelings' chart with characters stickers, to help children practice self-expression of emotions. Since the emotions generated in the brain, are experienced by the whole body, and according to Ekman (2011), the emotions, that are expressed through the facial expressions, the body language, and the attitudes, trigger changes in behavior and well-being [8].

Next, the second component of the workshop, requires working with children as one group to create dreamy ideas about their learning space using drawings, colours, collage; after refreshing their minds with brainstorming selections, interspersed by a fruitful discussion. This step role lies in motivating children to express their individual thoughts about their spaces' design, from their own perspective and according to their distinctive needs.

For the meantime, the virtual reality simulation is considered a very useful tool in neuroarchitecture; since it allows users to experience multiple spaces at the same time, without huge finances, allowing researchers to immediately study those different spaces influences on the users [9]. Simultaneously, to create the closest virtual experience to the real-life setting, and to bring its functioning idea closer to these young children's minds, the first alternative shown to them in the VR box is their actual learning environment, built as a typical virtual simulation to reality; to be followed by the virtual prepared alternatives of the studied architectural elements.

2.1. The setup

The study took place under the name of "Little architect's adventure" workshop, in a Montessori nursery & preschool in El-Rehab City, Egypt, called "Bubble Nursery". After a challenging filtration process between limited number of nurseries, due to the covid-19 conditions and the application's timing during the summer break.

The selected space "Junior Class A", (Fig. 1), was chosen due to the familiarity of children, from different age groups, with it. It was modelled typically as-built using 3Ds max software, imitating every detail to create an identical copy, to be then spherically rendered 360°, implemented in a 360 photo-viewer application 'VR Sync', that along with a VR box, transform the rendered image into virtual reality world. And then, 10 different alternatives from the actual existing interior setting were designed using the same steps, measuring five elements as follows:

Fig. 1. The actual classroom 'Junior Class A'. Source: Author.

- Lighting intensity

Two alternatives were prepared, where the changing variable was the intensity of the lighting unit between very weak intensity and bright and strong one.

- Colors temperature

Similarly, two alternatives were designed with two colour palettes, warm and Cool, according to the colour's temperature groupings, to be applied on every detail in the space with exaggeration to boost children's different experiences.

- Forms and shapes

This element was a little bit tricky, due to the space and area limitations; in the smooth-lines option, the design ended up changing only the edgy connections and walls outlines, openings, hanged boards, wallpaper, and storage units; along with the replacement of the carpet and furniture with more curvy options; while the sharp-lines option had minor changes in the furniture selections with more bold options.

- Ceiling height

Considering the existing space setting that already had a relatively raised ceiling height: 4 m clear height, the variation of this element swinged in both alternatives between 4.5 m height, and 2.7 m height; noting that it wasn't possible to create alternatives that are more distinct from the existing one, to respect the volume proportions logic.

- Nature integration

The core of this element variation was to stimulate multiple senses using the natural elements; the alternative integrating more natural elements needed to create a wider multisensorial experience, by maximizing the visual access to open expanded scenery of outdoor plants, some indoor plants, natural textures accessible to their hands, and also more nature-related activities, such as growing their own plants. In contrast with the other alternative that obscures even the visual access to natural elements, already present in the existing setting.

Simultaneously, a game-like template, (Fig. 2), was prepared for each element's alternatives, to be introduced to each child after diving virtually in those alternatives. The template consisted of a guiding 2D rendered snapshot of each alternative, and a set of emotions, themed with characters, suiting only the examined element and its expected range of feelings and reactions; taking into consideration children's raw emotional expressive skills, and respecting their growing mirror neurons' system[3].

Lastly, a set of innovative exemplary was employed in the brainstorming discussion that took place right after. It consisted of 16 different learning spaces from different projects, which opens the opportunity to monitor children's honest feedback about those design approaches, in a simplified architectural language. This phase helped unlocking the horizon for children's expression of their needs and preferences in their built environment, which took place as the following step, where they were asked to explain by drawing their dreamy optimum space design.

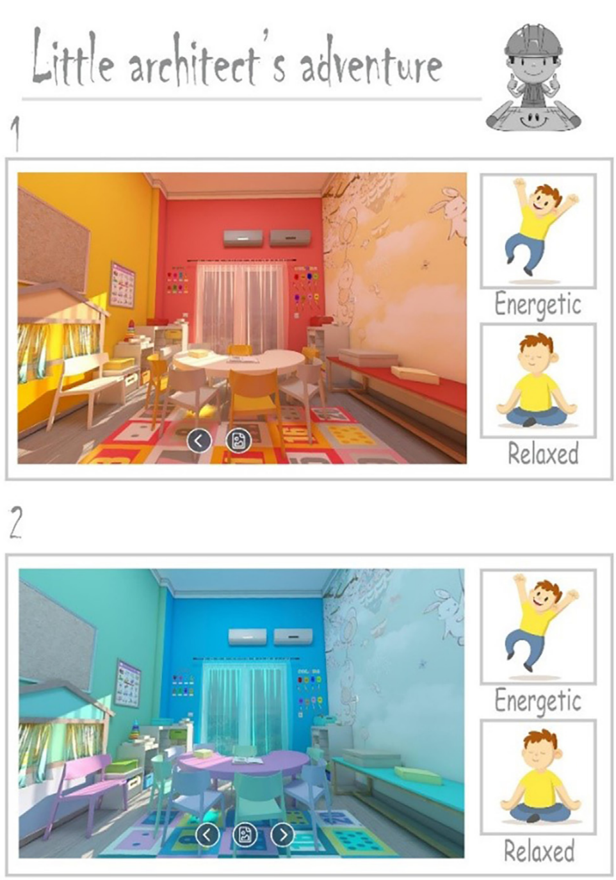

Fig. 2. The game-like emotions' template (Colours version). Source: Author.

2.2. The sample

The study sample was divided into different categories according to 2 different age groups:

- The first sample consisted of toddlers ranging between 3 and 4 years, (Fig. 3) their experiment was prepared to let them experience the first phase only, the individual activity, due to their young age, and limited attentional window [10].
- The second sample consisted of school age children (summer camp), between 5 and 7 years. This sample's experiment was prepared to let them experience the whole experiment, due to their age range that guaranteed a much more mature awareness and relatively easier expression of emotions and thoughts [7].

The school age sample showed interesting potential in the second phase; during the brainstorming discussion, their comments were documented through written notes, captured photos, and recorded feedbacks, along with the observation of their momentary reactions of the elements that strongly caught their attention, positively or negatively (Fig. 4). Moreover, they were given the chance to express their thoughts and needs from their viewpoint, using their raw drawing skills, along with the individual presentation in form of verbal explanation of what each one meant to present.

3. Theory

In the first place, the core of the implementation of this research work' aim took place through the investigation of the substantial impact the built environment, with its various elements, has on children's behaviour and performance, especially in the learning environments. This is in order to give the architects the newly-discovered scientific armament, that is capable of giving their design decisions a very different dimension of impact, yet so advantageous.

Basically, the effect of the built environment on individuals ranges between visible apparent effects, which could be studied by documentation, and more complicated effects, which requires in-depth study to extract the indirect impact on the human mind, the unconscious one, and what followed from effects on behaviour, mental and physical health [11]. For this reason, it was important to state multiple pivotal decisions, in the research preceding the experiment, according to literature scientific information, to be able to validate the whole research' results. Starting with the exposure type that was chosen to be experimented in the application;

Fig. 3. One of the toddler's sample experiencing the virtual reality. Source: Author.

Fig. 4. The children while expressing their ideas about their dream learning space. Source: Author.

according to Paiva (2019) the effect levels of the time and frequency of exposure to the built environment in shaping its impact on individuals, are classified as follows [11]:

- Short term exposure – short duration effect
- Long term exposure – long duration effect
- Short term exposure – Long duration effect

Thereupon, the short-term exposure, was the best scenario suitable for what this experimental research needs to accurately examine the validity of the theoretical literature knowledge. This is for so many reasons; topped by the 'immediate reaction' the short-term exposure produces, making it smoother to extract the actual produced reactions and emotions on the spot. This immediate impact does not require physical interaction with the environment, just a moment of exposure to the architectural stimulus; perceived through the senses.

> The ability to consciously process information is less than 1 % of the ability of unconscious processing. – Eagleman (2011) [12]

Accordingly, since the environmental stimulus affect the individuals on a subconscious level [13], it was important to consider all the possible variations that occur due to the short-term exposure, without conscious perception of the users, represented in the physiological changes, such as the heart rate' measurements.

3.1. The architectural elements

One pivotal issue was to determine the architectural features that can affect users on short-term level, and mostly shapes the built environment character. And hence, analyse these elements with reference to the recent neuroscientific driven architecture research. According to Paiva (2019) the most important elements, affecting the individuals on a short-term level of exposure are analysed as follows [11]:

- Light
- Color
- Forms & Shapes
- Ceiling Height
- Nature integration

3.2. The effects impacting children

Generally, the surrounding built environment produce multiple physiological and psychological effects, measured by the analysis of multiple parameters, explained below.

3.2.1. The emotional responses produced by the brain processes

According to the book "Discovering Psychology" by Hockenbury, the emotions are complex biologically based psychological states that are generated in the brain and experienced by the whole body; its role is to help the human body adapt to the environment around [14]. Similarly, the architectural elements can individually or combined induce the brain to react, generating specific emotional state.

According to Hockenbury, the emotional response involve three distinctive components as follows [14]:

- The subjective experience
- The physiological response
- The behavioral response

3.2.2. The vital signs

The physiological changes that occur in the autonomic and somatic nervous systems, as a result of the exposure to the built environment are many, but specifically, the heart rate is one of the variables that measure moment by moment changes in any vascular activity produced by the nervous system under any condition of psychological stress or relief [15]; and with the aid of the personal advanced devices, like smartwatches, it could easily be monitored and documented.

4. Results

Primarily, the research dived deep in the neuroarchitecture principles, argued from an absolute architectural viewpoint; with an intention of creating an integrated chart of architectural elements, including their variations and the claimed possible impact of each one of them, (Fig. 5). While in the same time analyzing the resulted data of the vital signs measurements under the supervision of the medical reference that arisen from the valuable collaboration with the family and pediatric medicine specialist in the Egyptian fellowship of family medicine, Dr. Sammer Magdy;

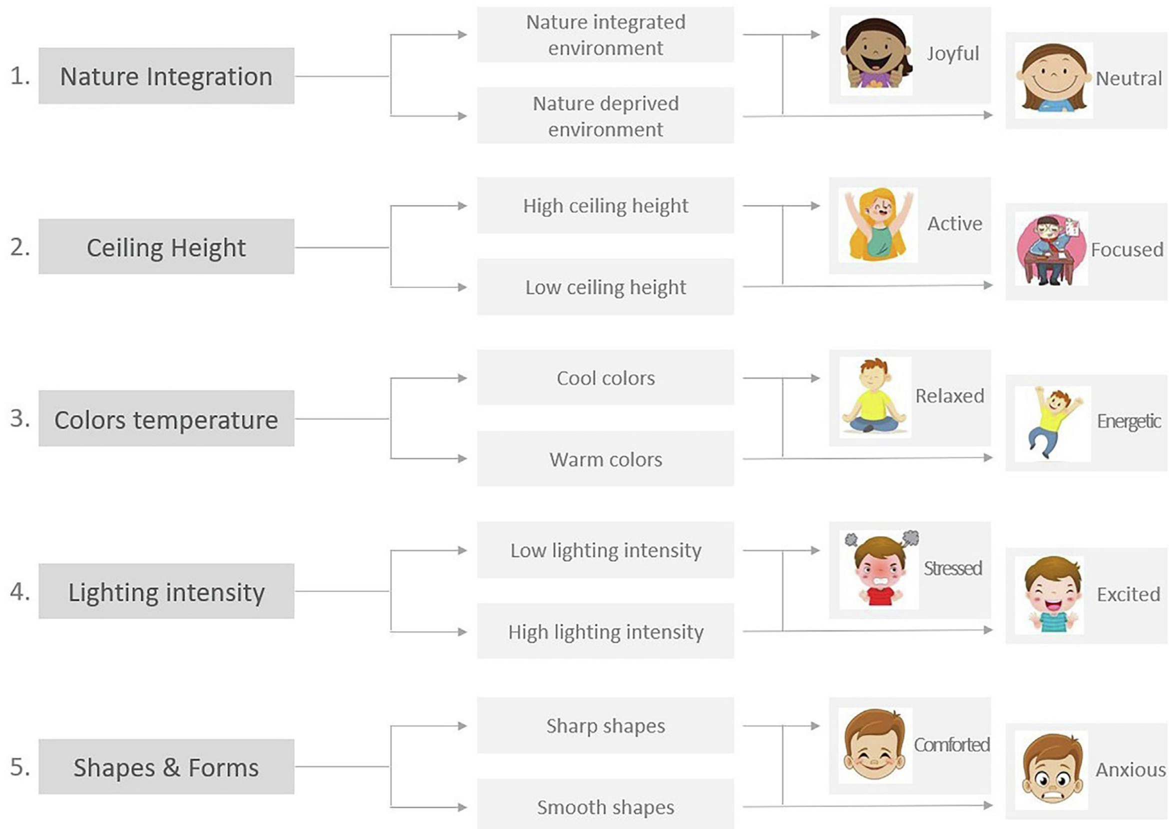

Fig. 5. The integrated chart of architectural elements and their equivalent emotions. Source: Author.

who briefly stated that the human autonomic nervous system is responsible of the translation of the body's response to the surrounding environmental stimulus into real physical reactions, including the heart rate variations.

Which means that when the human body is exposed to intense emotional response to his surrounding environment, it translates this energy into increased heartbeat due to the activation of the sympathetic system, and vice versa.

4.1. The physiological response indications

Following is a detailed combined explanation, of the measurement of children's heart rates while experiencing the various scenarios, their spontaneous reactions, and also their discussion about their feelings and personal assessments; starting with the statistical rated of the mean higher heart rates of the older sample (5–7 years) as follows (Fig. 6):

4.1.1. The nature integration

In agreement with the heart rates' records, children showed higher excitement, arousal, and stimulated senses, when placed in a space implying natural features, with natural light penetration inside the space. It is important to mention also that children's excitement alteration was easily monitored through their verbal enthusiastic expressions, their bodily reactions of hyper movements and even trials to touch elements inside the virtual reality, which matched perfectly the scientific stated data in previous research projects[16].

4.1.2. The ceiling height

In consistence with the heart rates records, the higher ceiling alternatives had a role in creating more excited and energetic behavior, consistently with the studied data, and also, adding a proof about the higher ceilings role in creating more excited and energetic behavior, compared to the low ones [17]. When switching to the other alternative of low ceiling, the majority of kids expressed strong perception of the difference, noting it as if the space became smaller.

4.1.3. The colours temperature

The majority of children have been spotted to have higher heart rates when exposed to the warm colors alternative, in comparison to the cool colors one, confirming the studied role of the warm colors in creating strong stimulation and boosting the adrenaline release in the brain [18]. Also, noteworthy that the colors element, with its both alternatives, was the most interesting element to children; as per their verbal description of every detail they were seeing with its color and how they evaluated it, and even their request to navigate inside it; which means that the attention given to the color's selection, along the design process, is a game changer, specifically when designing spaces for children.

4.1.4. The light intensity

While experiencing the two alternatives of the lighting intensity variable, the majority of children showed live excitement and intense change in facial reactions, when they were switched to the high light intensity right after experiencing the low intensity-one, also in consistence with their heart rates records, increased accordingly in the high intensity option.

4.1.5. The shapes & forms

The heart rates records supported the multiple studies caring about the effect of the smooth and curved lines in boosting more activity in some specific brain areas, which by its turn activates

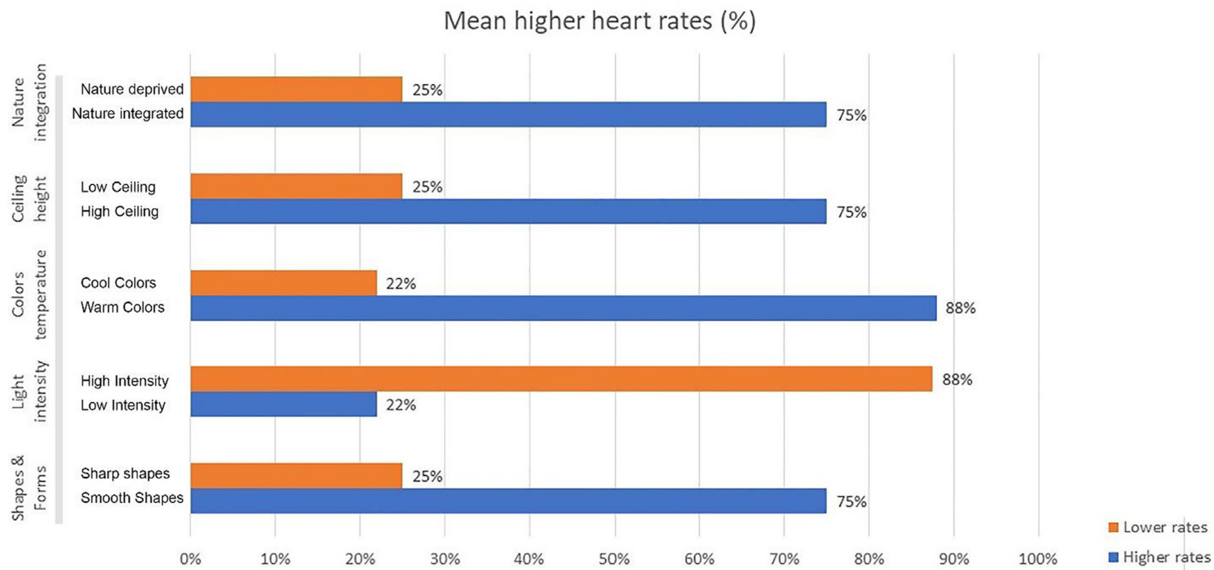

Fig. 6. The combined heart rates chart in each architectural element' alternatives. Source: Author.

the body's sympathetic system, and causes increased heart rates [19]. Also, children stated 'comfort' as description to their feeling inside the smooth alternative; in addition to the acknowledgment of a bunch of them that this alternative felt exciting and restful to their eyes, in a way that drove their curiosity to explore its features.

4.2. The emotional response indications

The children's emotional response was documented in a combined chart as shown in (Fig. 7), which matched perfectly the theoretical hypothesized results about the emotional response' variances; proving that the architectural features are indeed crucial in the design process. A substantiation to the distractedly empowering idea of the impact of the built space on the mental state and the generation of emotions, and hence the direct effect on creativity, attention, memory, learning, and well-being [20].

4.3. The children's input to the design principles

This part, regarding the workshop's second phase, yielded strong determinate preferences, from children, which were analysed, along with their drawn ideas too, (Fig. 8), then documented in the form of updated design tips, assisted by their involvement as follows:

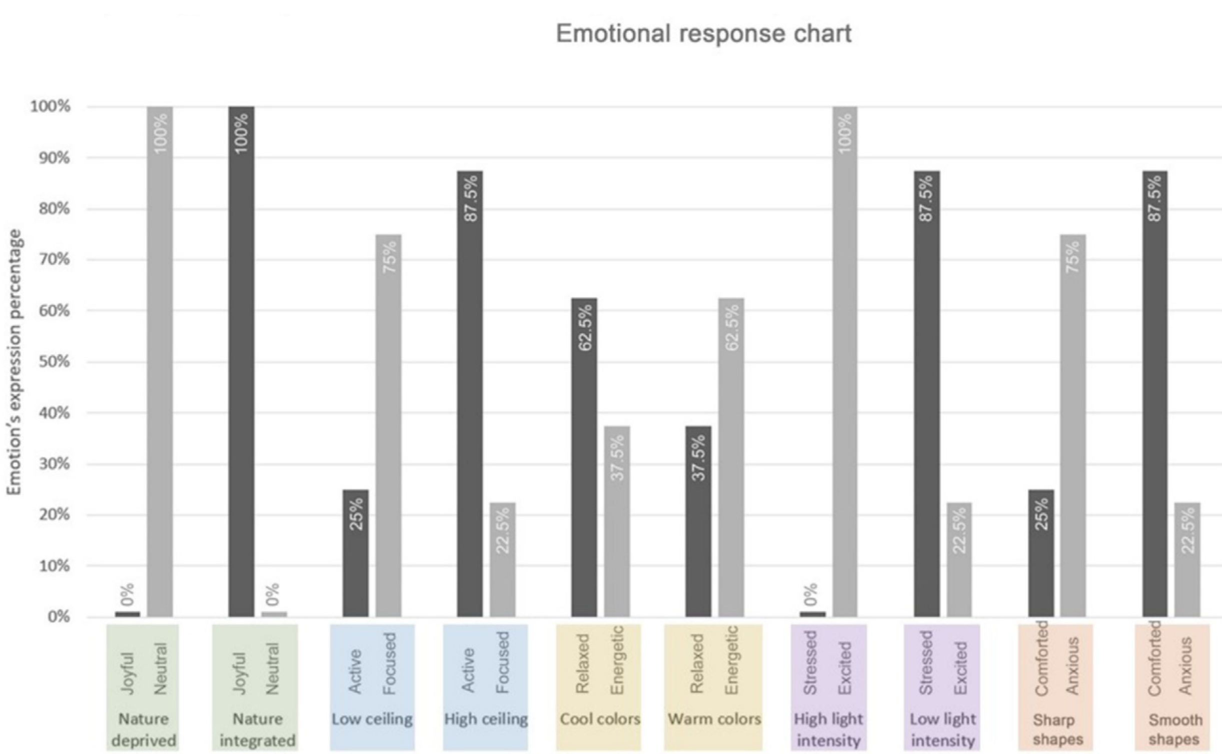

Fig. 7. The combined emotional response chart' results. Source: Author.

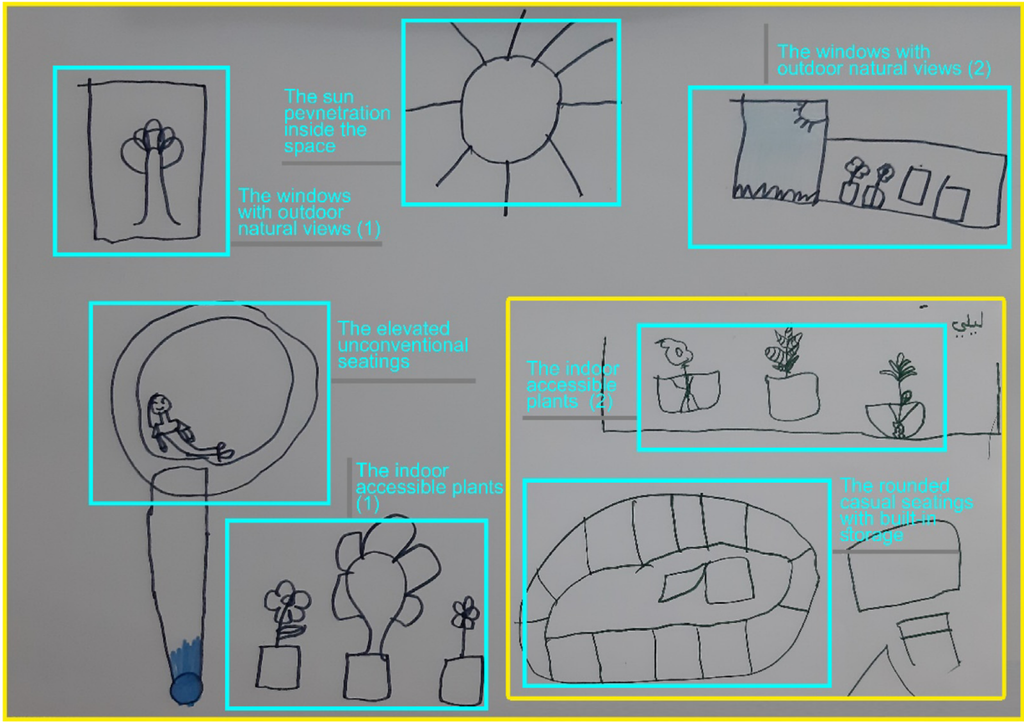

Fig. 8. The children's drawings output – Workshop' second phase. Source: Author.

- Natural finishing materials, whether in the flooring, ceiling, or even vertical louvers.
- Multiple flexible seating options in the same learning space, giving a sense of independence within the pre-planned order, e.g., comfy casual floor seating.
- Multi-leveled spaces give children the flexibility they need with a glimpse of curiosity
- Enclosures of any type, whether it is done with different levels, different flooring, or furniture encirclement, giving children safer feelings.
- The wise choice of always picking smooth curved elements starting from a circular layout of the space, if possible.
- Opposite to what is prevalent, the existence of a wide area permissible to draw on, is somehow confusing to children, and they find it hard to stay focused.
- Nature integration, taking into consideration a multi-sensorial experience of natural elements, not only visual accessibility.
- Child-sized furniture and storage units, giving children immediate autonomy feelings.

4.4. Significant contribution

As fruitful result of the research' experimental exploitation, that already produced compatible findings with the theoretical assumptions, a design impact guide was composed. In one of the firsts of its kind, a trial to empower the regular architect with this enlightening data, resulted from neuroarchitecture, where each architectural element is reviewed as follows:

- The specific brain areas that it affects
- The role this brain area has in the everyday behavioral outcomes
- The possible variables of this architectural element and its contradicting characteristics (if there are any)

while, for sure, relying on the limited architectural elements that have been already experimented in the study sample.

Accordingly, the design impact guide formed a relationship, (Fig. 9), between each studied architectural element, along with its possible variables, and the brain areas it could affect, as well as the affected daily behavioural outcomes by those specific brain areas, (Fig. 10).

Although, this research output has been experimented on the level of (Short term exposure – Short term effect), it is believed that the longer exposure is supposed to create long-term effect indeed, but it is also expected to flow in the same direction; which makes from those findings, still, an important milestone, but at the same time does not negate the importance of further research, and more profound experimental work.

4.5. Research limitations

Actually, this research confronted multiple challenging limitations, due to its nature, requiring the use of recent technologies; named briefly as follows:

- Regarding the limited existing tools, the research was obligated to create innovative replacements; topped by the assessment toolkit. It consisted of multiple features, complying with the available resources:
  - Virtual reality
  - vital signs measurement through smart watches
  - Emotional response' measurement templates
- The pandemic conditions that made it difficult to apply the application on a wide sample of experimenters.
- The limited attentional window of the toddler's sample made each child experience a varying number of alternatives, resulting in some inconsistency in its results. That's why the final interpreted findings focused mainly on the older sample's statistical results.

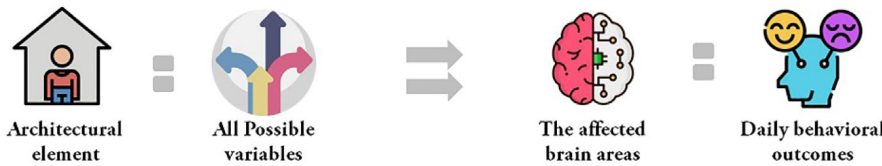

Fig. 9. The design impact guide functioning system. Source: Author.

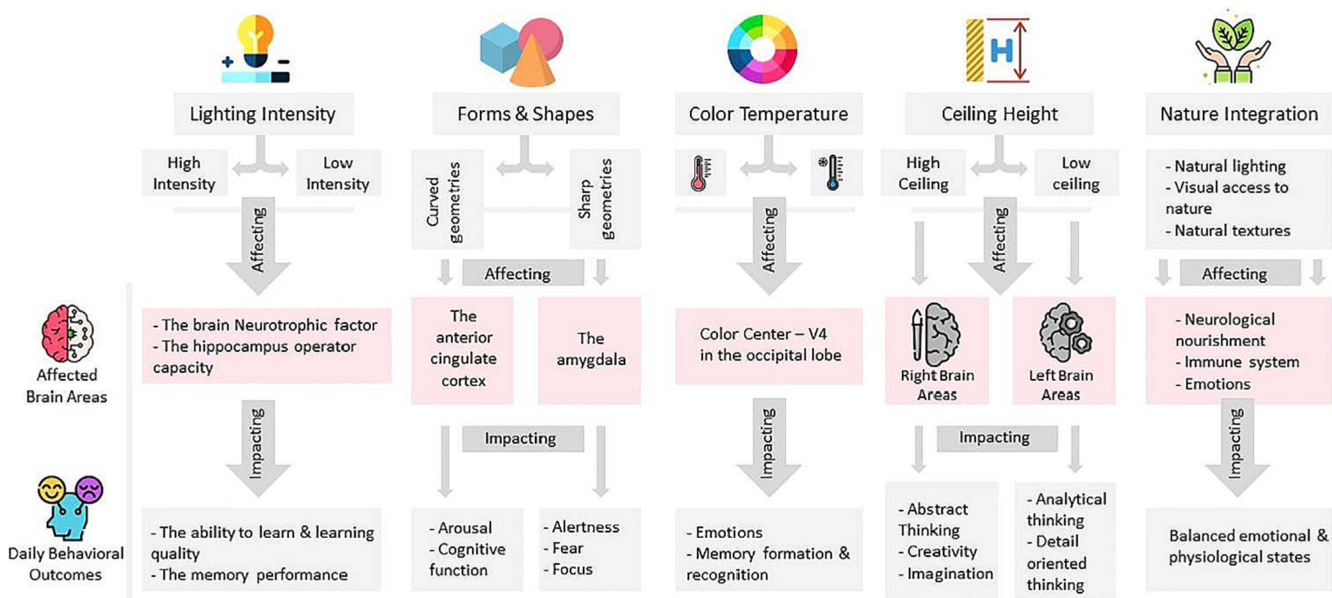

Fig. 10. The design impact guide' main highlights. Source: Author.

At the end, the research limitations slightly reduced the validity percentage of its findings; due to its special conditions. However, it is believed that they pushed the research to a more creative pathway in reaching its aim.

5. Discussion

Firstly, in the light of this research aim, a liveable experiment from the real-life practice was created; in an effort to relatively assess the credibility of the design principles and guidelines that were initially established so far in the field. Obviously, the initial planned set-up of the experiment confronted multiple limitations and difficulties; naming the complexity of the tools needed and the difficulties found in dealing with such young age of children.

However, this research experiment, despite that it has been simplified and specially composed to suit the available resources and conditions, it yielded many fruitful resources, which exceeded actually what was expected from it, and also shed light on the real potentials found in the involvement of the physiological measures in the design research processes, which impressively met the neuroscientific research' theoretical findings, so far.

And therefore, this practical research phase is considered an important milestone. It accredited a wide base of information to assist the design of children's learning environments; relying on architectural scientific measurements, thorough observations, and most importantly, the involvement of children input to configure their precise needs and preferences, which means putting the architects in their shoes, in order to understand their perspective about perceiving their surrounding environment.

6. Conclusions

This research work vision was to dive deep inside the promising emerging field of ''Neuroarchitecture", through the exploration of the architecture design capabilities in impacting the individuals behaviour, and well-being. Among multiple outputs, the design impact guide, created throughout this research, was developed in order to be able to create a successful contribution in this promising field's long research way coming up in this time, specifically tied up to the specific building type design of young children's learning environments. Moreover, since neuroarchitecture as an approach has stated that there is no recipe to be followed when designing with respect to its essential guidelines, its hopeful research progress is supposed to only produce organized guiding knowledge, to be taken into consideration in the architectural design phases; along with the respect of each project' uniqueness that includes the users, their cultural background, and the environment' special functions and conditions. That specific dilemma is what exactly has been the force behind the creation of the validated design impact guide. The guide which combined some of the most important inductions from the neuroscientific research findings related to architecture, along with this specific research' application findings; in haunt of the most possible validation to the complicated correlation between architecture and its scientific impact on the individuals well-being.

Conclusively, the recent neuroscientific research findings had shown an indispensable need for a harmonious plain linkage between the regular architect, who is willing to apply neuroarchitecture and the dense neuroscientific data and findings, that he shouldn't be obligated to deeply study. In order to empower him of efficient exploitation of all the pivotal potentials of the design decisions; giving him the opportunity of clearly stating the intended outcome he's wishing for from the environment he creates, and the execution of these statements. This new promising direction would assist the conventional design methodologies that mostly predetermine the design decisions according to favourable visual aesthetics, the personal preferences of the client or even the architect himself.

Lastly, the present times are witnessing a huge turning paradigm in the architectural research and practice; where the brave age of neuroarchitecture is beginning to crystalize; where people, rather than buildings, are at the epicentre. And since the smart cities' concept revolve around the citizen as the centre of attention, the realization of people' wellbeing would benefit greatly from the emerging interdisciplinary neuroarchitecture approach.

According to Vartanian, the vision of neuroarchitecture is the creation of an empirical framework for creating environments that can optimize human behaviour, health, well-being.

The most interesting issue is that the application of the insights of neuroscience on architectural research, until now, is far reaching. It promises the delivery of man-made built environments that measurably promote more effective and healthier activities; through the control of the exact needed impact on the brain dynamics, the bodies' response to these environments, and even some brain parts' continuous development.

7. Recommendations

Admittedly, the field of neuroarchitecture represents a fertile soil of research, where there is continuous release of neuroscientific findings, very appealing for integration inside the architecture world. Eventually the track of the research led to some future studies' suggestions, that are very alluring to explore, including:

- The specific research field, concerned with the learning environments' design, still needs further research, and wider experimental conditions, in order to produce more solid findings, reliable enough to be invested in future practice.
- For a more integrated research work, the collaboration between researchers from both fields; architecture and neuroscience, would surpass multiple limitations and produce promising results.
- This field in general has many untouched research scopes yet, that would be rather concerned with the different building types and the users' different backgrounds.

Data availability

The datasets used and/or analysed during the current study are available from the corresponding author upon reasonable request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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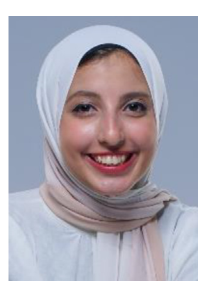

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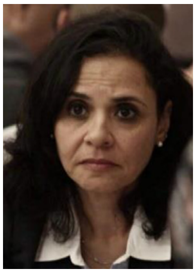

Shaimaa Mohammad Kamel is a Professor in Architectural Engineering Department, at the Faculty of Engineering, Ain Shams University, where she has been Head of Department for four years. She is currently a part-time faculty at the American University in Cairo. Since 1992, she has covered numerous teaching courses, developed course syllabi and supervised graduate theses. In her tenure, she has published research papers and participated in organizing international conferences. She's a member in the committee of excellence for Architecture at the Supreme Council for Culture. Additionally, Dr Shaimaa is part of the general assembly within the General Authority for Educational Buildings. Professionally, she has designed several buildings within private firm. She holds a PhD of Architecture from Ain Shams University.

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