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Breathing Spaces: Educating Indoor Plant Carbon Absorption through Interaction

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ABSTRACT

Climate change is a constant natural phenomenon. However, human activities over the last century have caused drastic changes well beyond its natural trajectory. Due to the unprecedented changes to the environment, rapid solutions to combat the consequences of climate change need to be implemented. Whatever strategy is adopted, education is key in order to achieve goals. Education interventions can be used to facilitate knowledge acquisition, skill development and build attitudes. Art-based education has become increasingly popular among educators, specifically in explaining scientific principles within a visualised environment using the latest technologies. Interior Design is a discipline that relies on visual thinking but lacks empirical work on using these developing technologies to capture student attention and transfer knowledge. This paper presents a study that explores digital art created to communicate the principle of using indoor plants as a means to purify air. The research is designed as a four-step action research project in which one cycle is completed. The results revealed that students were interested in the artwork, regardless of their level of prior knowledge of the subject.

Keywords: Building Performance, Carbon Absorption, Climate Change Education, Indoor Air Quality, Interaction.
JEL classification codes: I2, Q4, O3, Y9.

1. Introduction

Climate change is inevitable (IPCC, 2014, 2018). Since human interventions have caused drastic alterations within the natural trajectory of environmental events, we are threatened with unpredictable ecological changes. Confronted with the challenge to combat climate change (CC), education becomes crucial (Manzo, 2010; McKeown, 2002). Education interventions can facilitate knowledge, skills, attitudes and innovative thinking on ways to overcome any adverse impact of CC.

However, there are many challenges in developing and designing education programs specifically within the area of CC. Such programs started as a form of environmental education (EE).

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The foundation for environmental education was laid in two early documents which emerged respectively from the UNESCO-UNEP environmental education program conference held in Belgrade in 1975 (UNESCO, 1975) and the Intergovernmental Conference on Environmental Education held at Tbilisi (UNESCO, 1978). This conference made 41 recommendations that shaped Environmental Education in the following decades.

The use of the arts for education purposes is developing radically, specifically in climate change education (CCE). There is a growing tendency in the artistic fraternity to produce artwork that articulates concerns related to CCE. In response to the need for CCE, an international movement of artists forming synergistic associations between art and environmental science has rapidly emerged (Manzo, 2010; Nicholson-Cole, 2005). Among these trends, computer-based visualisations, interaction arts, uses of transmedia technology, tangible user interfaces and media facades have shown their impact.

Visualisation of climate change includes complex scientific phenomena and visual media are used which include both linguistic means and images (Brönnimann, 2002; Nicholson-Cole, 2005; O'Neill & Hulme, 2009). Further, reflecting on a similar study, Caitilin de Bérigny and Erika Woolsey (2012) emphasised that when information is presented in a visually pleasing and interactive manner, there is a better understanding among the public.

In architecture, CCE is primarily based on understanding, manipulating and evaluating building performance. Specifically, in a discipline where visual thinking and design skills are emphasised, teaching scientific principles is challenging. Technology is highly developed and virtual realities and digital media have altered ways of designing and visualising architecture. However, these visual aids are rarely used as education communication media. The study is conducted with the objective of identifying the positive impacts of using digital interaction arts to educate students, while providing a design tool guiding design decisions.

Maintaining indoor air quality is an integral component in any building performance study. The inclusion of indoor plants is a simple strategy that also provides many other physiological, psychological and aesthetic advantages for design. The major benefit is the ability of plants to absorb CO_2, which brings high levels of CO_2 to atmospheric equilibrium. However, it has also been observed that not all plants function equally in terms of carbon absorption. Leaf shape, branch distribution, colour and many other factors differ from plant to plant, leading to varying efficiency in photosynthesis. This digital artwork is based on enabling a better understanding of these differences when making design decisions to intervene with indoor plants.

2. Need for technology-based communication

Multiple methods of communication are required to address a topic as complex and as important as climate change (Koblin, 2011). In a study of audience reactions to climate change images, Saffron O'Neill and Sophie Nicholson-Cole (2009, p. 374) found that "the images that stimulated the greatest feelings of personal efficacy were those clearly showing what people can do personally". They also argued that "visualisation has great potential to be used more extensively as a means to communicate and stimulate public willingness to engage with the issue" (Nicholson-Cole, 2005, p. 258).

Art has significant potential for use in communicating scientific issues. For example, American scientist Joanna Rudnick collaborated with street artist Aaron De La Cruz to create a work of art that combines the science of cancer genomics and images of people whose lives are affected by genetic mutations in the BRCA1 and BRCA2 genes. Another interesting example is a collaborative project entitled Wind Map by Fernarda Viégas and Martin Wattenberg, respectively a computer scientist and an artist. These visualisations provide scientific data in interesting sequences with graphics and create original and varied images that are almost akin to art. Specifically in CCE, computer visualisations are a valuable resource for showing impacts with projections (Nicholson-Cole, 2005). Within a subject such as architecture, where visual thinking is highlighted, these academic conclusions provide support for educational interventions that rely more on visual media.

The visualisation process seems to be different for domain experts and non-experts. For a non-expert, it poses a substantial problem (Buchanan, 1992; Gough, DeBerigny, & Bednarz, 2014). For domain experts, it depends on the level of interaction data, interface design and cognitive function

(Carpendale, 2008; Chen, Floridi, & Borgo, 2014; Plaisant, 2004). In this study, a combination of expert and non-expert that would provide a basis in designing the visualisation.

With the development of new media, technologies also have evolved. Transmedia technologies, which rely on multiple digital technologies, have been used to create a greater impact. Especially when the subject concerned is complex in nature, such transmedia technologies seem to be used, including installation art, electronic art, digital art and video art installations (Wu, Gough, & Wall, 2012). These technologies are combined with video installations with the ability to communicate to a large audience with effective storytelling and message delivery technology (Bishop, 2005; McCandless, 2010).

This rapidly developing media art is worth testing in design studios, as it also needs to adapt to these trends. Already, the virtual reality and visualisation process is mainstream practice, and design studios risk becoming obsolete if they do not grasp these new needs and aspirations as they arise.

3. Research design

The selection of a research design that could provide the basis for systematic data generation and analysis was crucial. An action research model was developed for the study, providing a framework for all the tasks conducted during its implementation.

3.1 *Action research*

Exploring the term 'action research' itself can provide insight into its applicability in such situation. It is termed as 'classroom research' (Hopkins, 2008), 'self-reflective inquiry' (Kemmis & McTaggart, 1988), 'exploratory teaching and learning' (Allwright & Bailey, 1991) in different studies. Other terms, such as 'reflective inquiry' and 'evidence-based research', were also used to describe action research. Action research can include actions and reflection on a situation, which can lead to improvements to situations. Louis Cohen et.al. (2007) discusses in depth the various modes of action research and concludes that there are two ends: one on reflective practice and the other on critical practice.

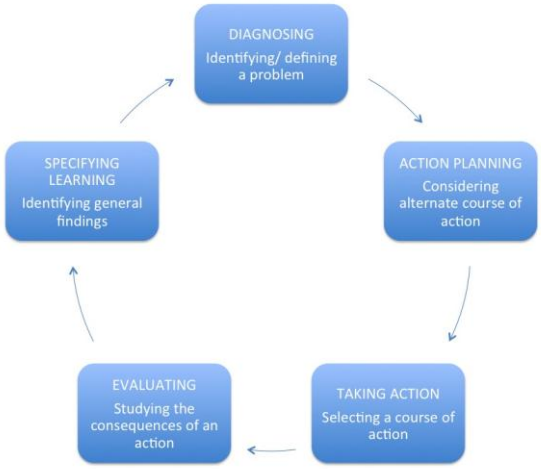

Figure 1: Five-stage action research model adapted from Sussman (1983)

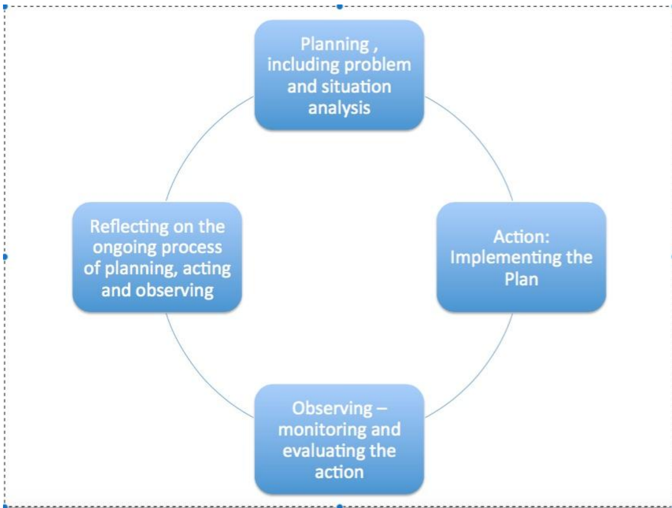

Figure 2: Action research model adapted from Schon (1984)

Whatever the approach and terminology used, there are some basic features common to its procedures. Zina O'Leary (2004) has clearly identified its salient features as being able to address practical problems, generating new knowledge through the process, and being participatory. A more democratic approach, it is made up of cyclic phases and, most importantly, it can initiate change.

Understanding the cyclic process is crucial in designing action research and there seem to be different interpretations of this cycle of activities. Kurt Lewin (1951) pioneered action research. His original model had six iterative phases: analysis, fact-finding, conceptualising, planning, implementation of action and evaluation. Based on the same flow of activities, a widely found model was developed by Gerald Sussman (1983) with five stages, as shown in Figure 1.

The reflective model developed by Donald Schon (1984) is more widely used in design disciplines and is diagrammatically presented in Figure 2.

Many differences may be considered as merely based on terminology but across the approaches four clear stages can be identified which can provide a premise for this study: planning an action, acting, evaluating and reflecting. Hence the planning in this study included the two steps of understanding the scientific principle and developing the digital artwork.

3.2 Action research model adopted

Based on the understanding of action research models and specifically focusing on the reflective model developed by Schon, a five-stage model was developed, as shown in Figure 3.

Step one was to understand the scientific principle of air purification by indoor plants. The interaction art was developed, based on existing research data on the ability of plants to abate air pollution. The action phase involved displaying the interaction art and collecting feedback. Analysing the collected data was also conducted during this phase. The reflection phase involved reflecting on the outcome of the research to explore the level of understanding and applicability to design.

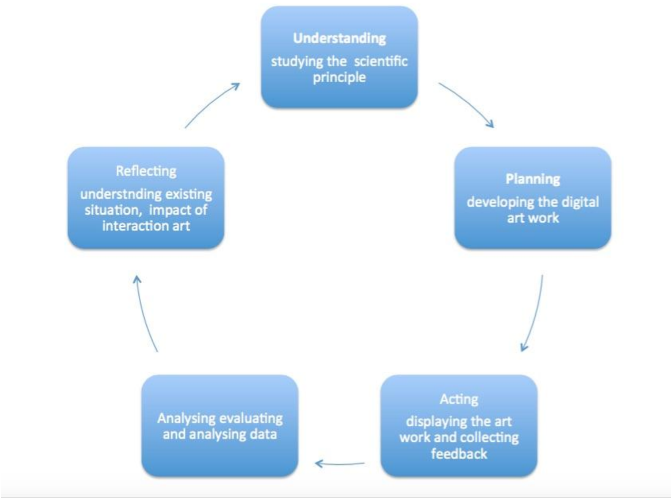

Figure 3: Action research model adapted by the authors

4. Air purification using indoor plants: Understanding the principle

The fact that plants use carbon dioxide in photosynthesis while emitting oxygen in the process is a well-known scientific principle. However, plants' ability to remove various other pollutants from the air in an interior space is not common knowledge. Reduction of the 'carbon footprint', increase in the energy efficiency of a building, and other environmentally friendly initiatives have gained considerable public and industry recognition through the Leadership in Energy and Environmental Design certification system administered by the U.S. Green Building Council (USGBC, 2011). In this system, credits are given for the use of indoor plants because of their phytoremediation quality, i.e. the removal of harmful volatile organic compounds (Yang, Pennisi, Son, & Kays, 2009), and their psychological benefits (Bringslimark, Hartig, & Patil, 2007; Lohr, Pearson-Mims, & Goodwin, 1996).

Apart from the use of plants, much other research is also being carried out to test the carbon absorption process. Caleb Stewart and Mir-Akbar Hessami (2005) explain that the carbon dioxide produced in fossil fuel combustion can be captured by amine scrubbing of the flue gases. However, they further explain that this is an expensive process and needs further development. They argue that the sustainability of the processes itself is crucial.

Carbon absorption capacity is correlated with environmental parameters (e.g, temperature, illumination, water availability) and biological parameters (Lerman, 1975) and has been the subject of scientific projects. NASA has taken a lead in plant research, exploring this ability with the crucial practical need to maintain air quality in space stations. NASA has conducted research for decades in this area and many of the scientific data used for this study are based on its findings (Rainey, 2017). B.C. Wolverton, Willard L. Douglas and Keith Bounds (1989), reporting on NASA's study, state that plants can play a major role in the removal of organic chemicals from indoor air. The work reported confirms that plant systems, and not the potting soil itself, are responsible for removing most of these chemicals. However, they argue that it appears that the part that microorganisms and plant roots play may be more important in the removal of chemicals than was previously believed (Wolverton et al., 1989)

The following scientific data is extracted from a visualisation done by the American Chemical Society (2016), based on the NASA findings.

- Aloe – This plant is excellent for increasing the oxygen level in the home because it absorbs carbon dioxide, formaldehyde and carbon monoxide. Nine air purifiers can be replaced with one Aloe Vera plant.

- Ficus (*Ficus elastica*) – This plant does not need a lot of light and can be easily maintained. It is quite effective in purifying the air of formaldehyde. But it should be avoided where there are pets or small children because its leaves may be poisonous.
- Ivy (*Hedera helix*) – This is an essential herb. Within six hours, it can remove 58% of faeces particles and 60% of the toxins in the air.
- Spider plant (*Chlorophytum comosum*) – This plant has an exceptional ability to perform photosynthesis under minimal light. It can absorb toxins from the air such as carbon monoxide, formaldehyde, gasoline and styrene. One plant is enough to clean the air in a 200-square-meter space.
- Snake plant (*Sansevieria trifasciata "Laurentii"*) – This plant is hardy and suitable for domestic use. It can perform photosynthesis under minimal light. It is ideal for use in the bedroom as it produces oxygen during the night.
- Peace lily (*Spathiphyllum "Mauna Loa"*) – This plant removes toxins from the air, including formaldehyde and trichloroethylene. NASA recommends 15 to 18 of these plants in an area of 500 square meters. For an area of 80 square meters, 3 to 4 plants are needed. Ideal for the bedroom.

Current research also reveals that there are many factors that affect the ability of plants to absorb pollutants. Size of the room, occupancy, lighting levels, plant pot soil and the plant itself are among the leading factors. The digital artwork developed depicts this scientific information by generating original artistic patterns.

5. Developing the artwork

In order to develop the artwork systematically, a phased process was adopted. Table 1 provides an outline of the phasing and the outcome in each step. Since there are a few impact factors that influence plants' ability to purify air, the development process reflected these complications by introducing different inputs and emphasising their significance, while gradually teaching the principle.

Table 1: Artwork development phases

Phase	Activity	Outcome
Initiation	Select 15 plants and develop the basic system	Can test the basic system to check the artwork graphics and selection of plants
Designing with size	Room size input is included	The plant can be selected and room size manipulated
Designing with people	Occupancy input is included	The plant can be selected and room size and occupancy manipulated
Designing with light	Lighting level input is included	The plant can be selected and room size, occupancy and light level manipulated
Designing with multiple plants	The option to select a combination of plants is included	The artwork allows a combination of plants to be selected to suit the need, and the graphic will depict the different plant leaves that have been selected.
Designing with different toxins	Other toxins are included	The artwork will also show the plants' ability to abate other toxic substances, such as formaldehyde, carbon monoxide and triglyceride.
Real-time experience	A real-time application with the impact of different plants on carbon levels.	A plant can be selected from the artwork and physically included in the room, enabling the real-time change in CO_2 levels to be checked.

This particular study was conducted during the initiation phase. For the initial system development, 15 plants that were recommended and researched by NASA were selected. A data matrix was developed to record a colour coding, leaf graphic intensity, clustering intensity, clustering generic pattern and graphic pattern. The rationale for colour coding and graphic intensity is to distinguish between the ability of various plants to absorb CO_2. The green intensity will be higher, reflecting that particular plant's capacity to absorb carbon, whereas the plants performing less well will have orange-coloured shading. The graphic intensity value is the number of leaf images used in the artwork which is also proportionate to the plant's carbon-absorbing capacity. The higher the capacity, the fewer leaves will be used, indicating that fewer plants can be utilized, while low-performing plants will show more plant leaves in the artwork.

Clustering intensity is the number of plant leaves shown in one cluster. This is a reflection of the leaf intensity of the actual plant. The clustering generic pattern is related to the way the leaves are connected in the plant. Every plant has its own way of connecting to a branch and the initial system will have five basic patterns to select from when inputs are fixed for a particular plant. The graphic pattern is a hand-painted image scanned and converted into a vector file as the source graphic for generating patterns in the artwork. Once this system is developed, it allows any plant to be included in the system, once the basic inputs are configured. During phase one, the system was developed as a web-based application.

6. Exhibiting for student responses

The exhibition was situated in a location where students spend their free time and conduct group studies. It was installed with a computer terminal as the control, and students were asked to use it and provide a response.

Figure 4: Breathing Spaces: Plant selection page, Authors

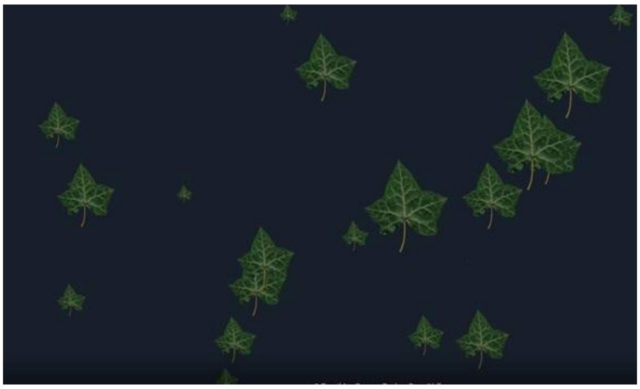

Figure 5: Breathing Spaces: Capture of English ivy artwork, Authors

Figure 6: Breathing Spaces: Capture of Elephant ear philodendron artwork, Authors

Figure 4 shows the plant selection page with the input for room volume, occupancy and lighting. During this stage, only plant selection was active for student response while room size and occupancy were kept as constants.

Depending on the students' selection, they generated various artworks. Figures 5 to 7 show some images captured from the artwork display. Every time a unique pattern was created and the hand-drawn leaf patterns provided the images, an

Figure 7: Breathing Spaces: Capture of Golden-pothos artwork, Authors

artistic quality of an original artwork. The system was built to capture the number of plants tried by each student, and they were also given the opportunity to print the captured images with their name inserted. Participants were given a questionnaire to fill out comprising six questions assessing their knowledge of plants' ability to absorb air toxins and six questions on the artwork. The exhibition was held for one day at that location.

7. Discussion

The responses from the students were analysed, using a quantitative data analysis method. The answers to the questions on prior knowledge of the principle were summed and used as one data series while the number of attempts with different plants was used as the other data series to establish relationships. The data processing was conducted and entered into the SPSS system and then a test of normality was conducted to find out whether the data distribution could be analysed using parametric methods. To establish relationships, the paired sample t-test was conducted, using different data series.

7.1 Test of normality

The statistical analysis selected is based on Parametric Methods. The hypothesis testing in parametric methods requires that the data series be normally distributed to provide better results. The Shapiro-Wilk Test is used to test normality. If the sig. value of the Shapiro-Wilk test is greater than 0.05, it indicates that the dependent variables are normally distributed.

The hypothesis of the Normality test

H_0 : Knowledge marks of the students are normally distributed, attempts of the students are normally distributed

H_1 : Knowledge marks of the students are not normally distributed, attempts of the students are not normally distributed

Table 2: Data generated for normality tests for knowledge marks and attempts

Tests of normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	Df	Sig.	Statistic	Df	Sig.
Knowledge Mark	.195	24	.019	.939	24	.152
Attempts	.142	24	.200*	.961	24	.459

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

According to the normality test results (Shapiro-Wilk Test) as given in Table 2,
Knowledge mark
Sig. =0.152
0.152> 0.05
Sig.> 0.05
Attempts
Sig. =0.459
0.459> 0.05
Sig.> 0.05

Thus, H_0 cannot be rejected. So the dependent variables are normally distributed. Since the marks and attempts are normally distributed, data can be analysed using parametric tests.

7.2 Paired sample test

Paired sample T-test procedure compares the means of two variables for a single group or the means from two matched groups. In this analysis procedure, each subject has two measures. In this study, the two measures are the student mark for knowledge and the attempts. The procedure computes the differences between the values of the two variables for each case and tests whether the average differs from 0, which is termed a two-tail test.

The following conditions and assumptions for Paired Sample T-tests are clearly met in these data sets:

- The sample could represent the target population
- The dependent variable under the interest is either an interval or ratio scale
- Independent variable comprises two matched pairs
- Distribution of the differences in the dependent variable between the two related groups should be 'normally distributed'

When testing for hypothesis using SPSS software, the first Null Hypothesis and the Alternative Hypothesis should be stated.

H_0 : Knowledge marks and Attempts are not correlated

H_1 : Knowledge marks and Attempts are correlated

If null and alternative hypotheses are statistically elaborated, they would be:

$H_0 : \mu_1 - \mu_2 \leq 0$

$H_1 : \mu_1 - \mu_2 > 0$

μ_1 = Mean of Knowledge mark

μ_2 = Mean of Attempts

Table 3: Paired sample statistics for knowledge marks and attempts

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Knowledge mark	7.37	67	17.288	2.112
	Attempts	6.11	67	16.097	1.967

Table 4: Paired sample correlations for knowledge marks and attempts

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Knowledge Mark & Attempts	67	.343	.000

The Paired sample statistics output repeats the data that is entered, and the generated tables are given in Table 3. The above data adds the information that the knowledge mark and attempts are not significantly positively correlated, as the correlation is only 0.343. This statistical figure could be elaborated as the knowledge level is not a strong factor in determining student interest in participating in the artwork.

8. Conclusions and policy implications

The study was conducted in order to explore the students' knowledge levels and the effectiveness of communicating scientific principles to them. The study was not expected to identify concrete conclusions but rather to acquire an understanding of perceptions.

de_Berigny and Woolsey (2012) argued that better public understanding of climate change can be accomplished by presenting science in a way that is interactive, visually sophisticated and educational. They provided evidence of many works in which they have used interactive techniques to effectively communicate the message on the consequences of climate change. Thus the use of this interactive digital artwork could become a means of conveying a scientific principle effectively to both design students and novices to the subject area.

The significance of this study is that it allowed a method to be developed to transform a scientific principle into a digital media artwork. Generally, digital art depends on mathematical inputs and in this instance the inputs were given on a rationale of visualising a few scientific principles. This digital media artwork could also assist in exploring an interesting strategy for teaching scientific principles while arousing curiosity and also serving as a design tool.

This interest in the first step, merely looking at plants, could be enhanced with the subsequent stages. Specifically, with different parameters such as room size and occupancy, the students get more opportunity to explore and try out various combinations. This digital media artwork could also improve their knowledge. Thus the system allowing for other input plants with scientific data could become an active platform for gathering and disseminating scientific data.

Research on the carbon absorption capacities of indoor plants is being conducted widely but is scattered. The main contribution of this research is its synthesis of the research data on plants' ability to convert CO2. The development of a visual learning tool in form of an interactive digital artwork would be the first such technology-based approach used in interior architectural studies. There are plans to develop this tool further for use in both teaching and designing. The artwork developed on a large scale could also be used as a public display, allowing the knowledge to be communicated to a larger population as an awareness campaign.

This study highlights the need for policy makers to look into how curriculums are developed. The conventional partition between science and art is merely an illusion. Combining them could enhance the communication of scientific principles through visualisations. For art education, the significance is introducing science as a topic of interest for artworks and discussing matters that are vital to the survival of the earth's ecological system. Increased public awareness could be used to pressure policy makers for more opportunities to interact with nature in physical development. Specifically, in a time when people are forced to live in enclosed spaces, this understanding of bringing nature into interior spaces for a crucial need could also become an eye-opener for policy makers, encouraging them to take bold decisions and even to legislate for more green natural spaces to be incorporated into built habitations.

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