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The first large-scale indoor tropical garden with Brazilian native tree species: Challenges and lessons

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ABSTRACT

This commentary reports the challenges faced and lessons learned during the formation of the first large-scale tropical garden inside a building with native tree species in Brazil. This garden, set entirely over cement slab, is inside the Albert Einstein Education and Research Center (AEERC) – Campus Cecília and Abram Szajman in São Paulo city, and comprises 11 tree species, ten of which are native to the Atlantic Forest. The indoor environment, in the shape of an atrium, is controlled and isolated from the external environment, which imposes a unique and new habitat for those tree species, especially considering that this garden is shared with people during their daily activities. Over one year, we followed the growth and development of 95 trees and noticed that the acclimation potential varied among species as well as the susceptibility to pest and disease outbreaks and low temperature (due to an imbalance in the air conditioning system), which were identified as the main limiting factors. Among the species monitored, *Lafoensia glyptocarpa* was the most sensitive to mites, aphids and mealybugs, and effective and rapid phytosanitary management was crucial for maintaining a healthy garden. *Aspidosperma polyneuron, Eriotheca candolleana, Holocalyx balansae, Poecilanthe parviflora* and *Euterpe edulis* were the species with the most acclimation potential to the new environment, which was based on leaf area development. On the other hand, poor acclimation was observed for *Calycophyllum spruceanum*, which was replaced two years after the initial planting. As an important lesson, continuous monitoring of both plants and the environment is needed to enhance our knowledge and management of indoor tropical gardens.

Introduction

Indoor gardens are sources of inspiration for people, providing fresh air and a calming landscape that certainly contribute to wellbeing and the improvement of working conditions when they occur in business buildings and research centers. Green areas offer urban populations opportunities for restoration (Grahn and Stigsdoter, 2003), and in recent years, contact with nature has received increasing attention as a way of reducing stress (Dolling et al., 2017). Although Brazil does not have a great tradition of indoor cultivation of crops or even ornamental shrubs and trees, which is certainly associated with the predominantly tropical climate, a striking example is the indoor garden at the Albert Einstein Education and Research Center (AEERC), in the metropolis São Paulo SP. This center is dedicated to training and research in health sciences, with classrooms for teaching undergraduate and graduate students, laboratories, conference rooms, an auditorium for 400 people and other facilities for carrying out state-of-the-art research (Grunow, 2022), with all of these environments surrounding the atrium garden (Fig. 1). In fact, such an indoor garden is the first one designed almost entirely with tree species native to Brazil inside a controlled environment.

The garden

Isabel Duprat conceived the project with the idea that the green areas were remnants of the location, where trees and palm trees would populate the slopes and the plateau, as if the building had been carved from this terrain and the vegetation that was there could be transformed into gardens permeating and surrounding the blocks (Fig. 1A,B), connecting interior and exterior to bring life to the building. Various types of ornamental plants along with bamboos and taller tree and palm tree

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Fig. 1. (A) Longitudinal section of the building (West-East); (B) Atrium garden - schematic plans: above: initial design from the architecture team; below: redesign proposal by the landscape team, with planting areas in green, living areas in yellow, restaurant area in light blue, amphitheater in orange and with arrows indicating the expansion of the garden towards the restaurant area; (C) Atrium garden seen from an upper level. Photo: Manoel D. Leão Neto; (D) General view of the atrium garden, with the restaurant in the foreground. Photo: Fernando Guerra; (E) Atrium garden - amphitheater. Photo: Fernando Guerra; and (F) Studying areas surrounding the atrium garden. Photo: Fernando Guerra.

species bring a dynamic and different perception of light and shade to the spaces created in the garden (Fig. 1C), attracting the public's attention and allowing for a possibility of sensations, calming, restful, promoting creative thought and harmonic togetherness of trees and people.

The indoor garden occupies an area of 1320 m^2 (Fig. 1C), of which 700 m^2 is the planting area, and it is basically divided into three levels: the lower level, with the restaurant (Fig. 1D); the intermediate level, with a small water feature and an amphitheater (Fig. 1C,E); and the upper level, close to the main entrance (Fig. 1A, right side). This indoor garden ended up becoming the central space of the whole building, acting as an interactive environment in which students, researchers and visitors can enjoy an open space to discuss ideas, refresh their minds, and have a coffee break and even meals at the restaurant (Fig. 1D-F). Recently, Oh et al. (2022) reported that frequent garden visitors identified themselves as a part of nature, and those who enjoyed being in nature had stronger social cohesion. This was the overall aim of the indoor garden inside the AEERC. In fact, fewer opportunities to experience nature in cities may reduce opportunities for social engagement and weaken social cohesion (Oh et al., 2022).

Enabling this indoor garden has only been possible because the landscaping project started concomitantly with the architectural project (Fig. 1B), which was key to guaranteeing that the plant needs were prioritized during the process, considering all the necessary adjustments in consulting projects, such as structure, irrigation, high-pressure misting, lighting, drainage, and electrical and plumbing engineering. For instance, given that the whole indoor garden was set on cement slab, the structural project was meticulously designed to meet the soil and vegetation load requirements as well as to guarantee the necessary soil depth and free horizontal spread (free of upstand beams) for the development of the plant root system. The landscaping project has even proposed to increase the planting area and replace the narrow planters that were initially proposed in the architectural project, redesigning the atrium geometry to allow the use of trees and to be able to create living spaces and walks (Fig. 1B), so that the space would be a "place" to be lived and enjoyed, not just a contemplation garden with an amphitheater. Another aspect carefully considered during the project was the necessary air temperature and relative humidity ranges that would contemplate both the well-being of people and plant development. The target was set at approximately 24 °C for the temperature and 60 % for relative humidity (not lower than 50 %).

Tropical tree species: from the nursery to the building

The garden has individuals of ten tree species native to the Atlantic Forest and one exotic species (Table 1), specifically selected to match their light demand and the light availability in each area of the garden. During the project phase and based on the light distribution inside the building, the landscaping team asked to reduce the density of the skylight glass fritting to allow more light into the atrium, improving the conditions for the development of plants. The individuals were moved to the building after a two-year acclimation in a nursery of 2500 m^2 (50 × 50 m, 8 m high), built exclusively to provide plants with similar light levels that would be available in the building atrium. For that, a 50 % shade cloth was used. In the nursery, the individuals were automatically irrigated and were grown in bags or fiber containers of 100, 250 or 500 L, depending on the size of the tree. Care with root balls was taken to reduce the stress of transplantation. The plant responses to low light were monitored throughout the acclimation period, and the good physiological state, plant size and structure were elements that supported the final choice of species for the planting phase of the project. We could argue that this was the first challenge faced by the team because any replacement of plants after moving trees inside the building would be a delicate procedure.

Table 1
Tree species (scientific and common names, and family) used in the indoor garden of the Albert Einstein Education and Research Center (AEERC), São Paulo SP, Brazil. Their acclimation potential based on changes in leaf area is indicated: (++) high acclimation, with large increase of leaf area; (+) acclimation, with increase of leaf area; (Ø) null acclimation, without modification of leaf area; (–) negative acclimation, with reduction of leaf area. When there is a common name in English, it is cited.

Scientific name	Family	Common name (Portuguese/English)	Acclimation
Aspidosperma polyneuron Müll. Arg.	Apocynaceae	Peroba rosa	++
Calycophyllum spruceanum (Benth.) K. Schum.	Rubiaceae	Pau mulato	–
Eriotheca candolleana (K. Schum.) A. Robyns	Malvaceae	Catuaba	++
Holocalyx balansae Micheli	Fabaceae	Alecrim-de-campinas	++
Inga spp.	Fabaceae	Ingá-feijão/Inga	–/+
Lafoensia glyptocarpa Koehne	Lythraceae	Mirindiba	+
Plinia cauliflora (Mart.) Kausel	Myrtaceae	Jabuticabeira/ Brazilian grapetree	+
Nectandra megapotamica (Spreng.) Mez	Lauraceae	Canela	Ø
Poecilanthe parviflora Benth.	Fabaceae	Coração-de-negro	+
Terminalia neotaliala Capuron*	Combretaceae	Sete-copas-africana/ Madagascar almond tree	+
Euterpe edulis Mart.	Arecaceae	Palmito-Juçara	++

* Exotic species.

Tropical tree species: acclimation to the new environment

As the indoor garden was assembled approximately nine months before ending the construction of the AEERC (in March 2022) for logistic reasons, the plants shared the space with the workers that were painting and plastering the interior walls, installing accessory equipment on stairs and areas close to the garden, and using chemical products for cleaning and other purposes, which were dispersed through the air. The result was excessive dust deposition and occasional paint drops on the plant foliage, which further reduced light interception by plants and likely hindered their photosynthesis and transpiration, fundamental physiological processes for the absorption of nutrients, CO_2 uptake and growth, also making the plants more susceptible to pest attack. This was the second challenge faced by the plants. To minimize this situation, a low-pressure washer was used to wash the leaves and prevent excessive dust deposition. Additionally, high-pressure misting nozzles installed at the top of tree canopies were activated during this phase of construction to reduce the effect of accumulated dust and refresh the garden environment because the indoor temperature was too high because the air conditioning system was not working yet. Such nozzles were anticipated during the project phase to increase the relative humidity in case of a significant drop. Currently, air relative humidity levels are within the expected range, and nozzles are not necessary at this moment.

In projects of such magnitude, we should also be aware of the interaction between roots and growth substrate, which must be fertilized and irrigated properly. Fertilization was performed by leaf spraying with fertilizers composed of boron (0.2 %), nitrogen (1.0 %) and orange oil (Botanix Terpex, Technes, São Paulo SP, Brazil) and decanted pyroligneous extract enriched with calcium (6.1 %), magnesium (0.7 %), manganese (1.8 %), zinc (0.5 %), cupper (0.2 %) and boron (0.1 %) (Pirobon Max Ca and Max Mn, Insuforte Nutrição Vegetal, Itapetininga SP, Brazil). Seaweed extract (Acadian, Acadian Plant Health, Dartmouth NS, Canada) was also used to enhance plant establishment by stimulating root growth, and a biological product based on *Trichoderma harzianum* (Trichodermil, Koppert do Brasil, Piracicaba SP, Brazil) was applied to soil for protection against root diseases. As organic matter added to soil can generate excessive heat close to the roots during its degradation, soil temperature must be monitored. In addition, the availability of water is another critical factor, as the transplanted tree species had a concentrated and compacted root system. In this way, plants were especially sensitive to variations in soil moisture before the inauguration of the building (in March 2022), when the air conditioning system was not operating and the internal air temperature could easily exceed 30 °C at noon during the spring and summer seasons. The consequence of this imbalance between water supply and demand caused defoliation in more sensitive species, such as *Nectandra megapotamica*.

Another challenge faced by the plants was the temperature shift. If excessive heat was an issue in the atrium area during the planting and establishment periods, the opposite happened after the air conditioning system was fully operating. Once the building was inaugurated, the temperature dropped to approximately 17 °C at the lower part of the garden, which was much lower than the levels set during the project phase. This imbalance in the air conditioning system directly impacted the three individuals of *Inga* spp., two of which showed a significant reduction in leaf area, and the third died. Once air temperature was adjusted to the project levels, which took eight months after the building inauguration, the remaining *Inga* spp. plants regrew, and another individual was planted to replace the one that died.

Despite the abiotic factors representing a challenge for plants in indoor gardens, we believe that the main limiting factor for trees in this project was the biotic stress induced by mites (*Tetranychus* sp.) on *Euterpe edulis* and *Lafoensia glyptocarpa*, aphids on *Aspidosperma polyneuron, Calycophyllum spruceanum* and *L. glyptocarpa*, mealybugs (*Pseudococcus* sp.) on *Inga* spp., *Poecilanthe parviflora* and *L. glyptocarpa*, and whitefly (*Bemisia* spp.) on *N. megapotamica* leaves. Initially, the most attacked plants were those close to the main entrance to the building – in this case, *L. glyptocarpa* trees. Inappropriate control of pests in *L. glyptocarpa* – especially mealybugs – caused their dispersion throughout the internal area, reaching *P. parviflora* and the other *L. glyptocarpa* trees on the second level of the garden. It was known by the landscaping team that biotic stress, especially mealybugs, which are common in indoor gardens of any magnitude, would demand constant attention and preventive care. Duprat's team issued regular alerts in this regard during follow-up visits after the end of the planting phase. Such actions had already been carefully proposed during the project phase to guide the company that would oversee garden maintenance. Obviously, phytosanitary control of indoor plants must be carried out with great care and responsibility, and the initial options were biological and low-risk products. However, since effective measures took a long time to be addressed, biological products were inefficient in dealing with the high biotic pressure – with the pests colonizing either stems or leaves – leading to the use of chemical products for pest control. The most injured plants almost completely lost their foliage, and the recovery of the leaf area took months. As a great lesson, the building maintenance team learned that the monitoring of pests and diseases must be frequent and that effective control actions must be taken as soon as possible. If preventive care is taken, biological products could be an option for controlling pests, which is a hypothesis to be tested and a way to avoid the use of chemicals inside the building.

Regardless of biotic or abiotic pressures, plant growth is governed by the acclimation to this new environment, where seasonality does not exist once air temperature is relatively constant inside the building and there is no rain or large variation in soil water availability due to daily irrigation. Light intensity inside the building is low and conditioned by the daily movement of the sun above the building's skylight, with significant spatial variation between the north and south faces. As a reference, the maximum photosynthetically active radiation (PAR) measured in areas on the north and south faces of the building were 270 ±203 and 981±191 μmol m^{-2} s^{-1}, respectively, which is on average approximately 12 % and 45 % of the maximum level found outdoors on a summer day without cloudiness, *ca.* 2200 μmol m^{-2} s^{-1}. Among the species studied and over 12 months of observation, we found a low acclimation potential for *C. spruceanum* and *Inga* spp. (Table 1). These species always had small canopy sizes and low leaf areas, and *C. spruceanum* was especially susceptible to aphid attack. The only exotic tree species used in the indoor garden – *Terminalia neotaliala* – grew satisfactorily during the monitoring period, although its canopy structure with branches naturally disposed in organized horizontal layers changed over time from a spreading to an irregular and pendant form. Other species that presented similar changes in their regular crown shape were *Holocalyx balansae* and *P. parviflora.*

From a total of 95 trees monitored, comprising 11 species, only eight *C. spruceanum* trees were replaced by *Ptychosperma elegans*, a procedure performed 23 months after the initial transplanting. One individual of *Inga* spp. was also substituted by another one of the same species after 18 months of initial transplanting, once the imbalance of the air conditioning system was solved, as previously mentioned. After the planting phase carried out by Duprat's team was complete, another company took over the maintenance of the garden, and the following activities are ongoing: soil loosening; fertilization; preventive use of biological and low-risk products for pest control – whose effectiveness must be proven in the medium to long term; pruning; leaf washing with garden hoses to remove dust that naturally accumulates over time; and evaluation of how plants are developing. From time to time, the maintenance procedures will also have to encompass the washing of the skylight to guarantee that dust and dirt will not accumulate outside, hindering the entrance of light.

Perspectives

As a final lesson, we emphasize that the continuous monitoring of this indoor garden is important not only for the preservation and well-being of the people who use the AEERC facilities but also for the increase in knowledge about how tree species native to the Atlantic Forest will develop in a climate-controlled environment without seasonal variation in air temperature, air relative humidity and soil water availability. Would the natural phenology of those tree species be preserved? Would plants flower and bear fruit as they do in the wild, even without the help of pollinators? Answering questions such as these is essential for maintaining the indoor garden and accomplishing its primary objective of improving quality of life in large cities.

CRediT authorship contribution statement

Rafael Vasconcelos Ribeiro: Conceptualization, Writing – original draft, Writing – review & editing. **Nathalia Fonseca:** Writing – review & editing. **Manoel Dubeux Leão Neto:** Writing – review & editing. **Isabel Duprat:** Writing – review & editing. **Maria Andréia Delbin:** Writing – review & editing.

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.

Data availability

Data will be made available on request.

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