Research paper

Growing architecture

Explore Lab

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CONTENTS

◀ **1** A vernacular example: a living-root bridge in India (Ludwig, 2023)

Abstract

This research project – completed as part of my graduation project for the MSc Architecture, Urbanism and Building Science at TU Delft – set out to investigate the architectural potentials and limitations of Baubotanik design through the following questions: ***What can Baubotanik do?*** and ***What do spaces need?*** By analysing both precedents and spatial requirements across temperate and tropical climates, the study identifies **seven key design considerations** for the strategic application of Baubotanik in spatial design, with the aim to provide designers concrete advice in this experimental field. The findings demonstrate that **climate**, **seasons**, **tree species, environmental control** and **spatial typologies** play an important role in the viability and success of a Baubotanik project. We have concluded that Baubotanik is not suitable everywhere, with tropical environments and (semi-) outdoor spaces showing greater compatibility.

The findings in this research paper provide an important starting point for the upcoming design project.

INTRODUCTION

01

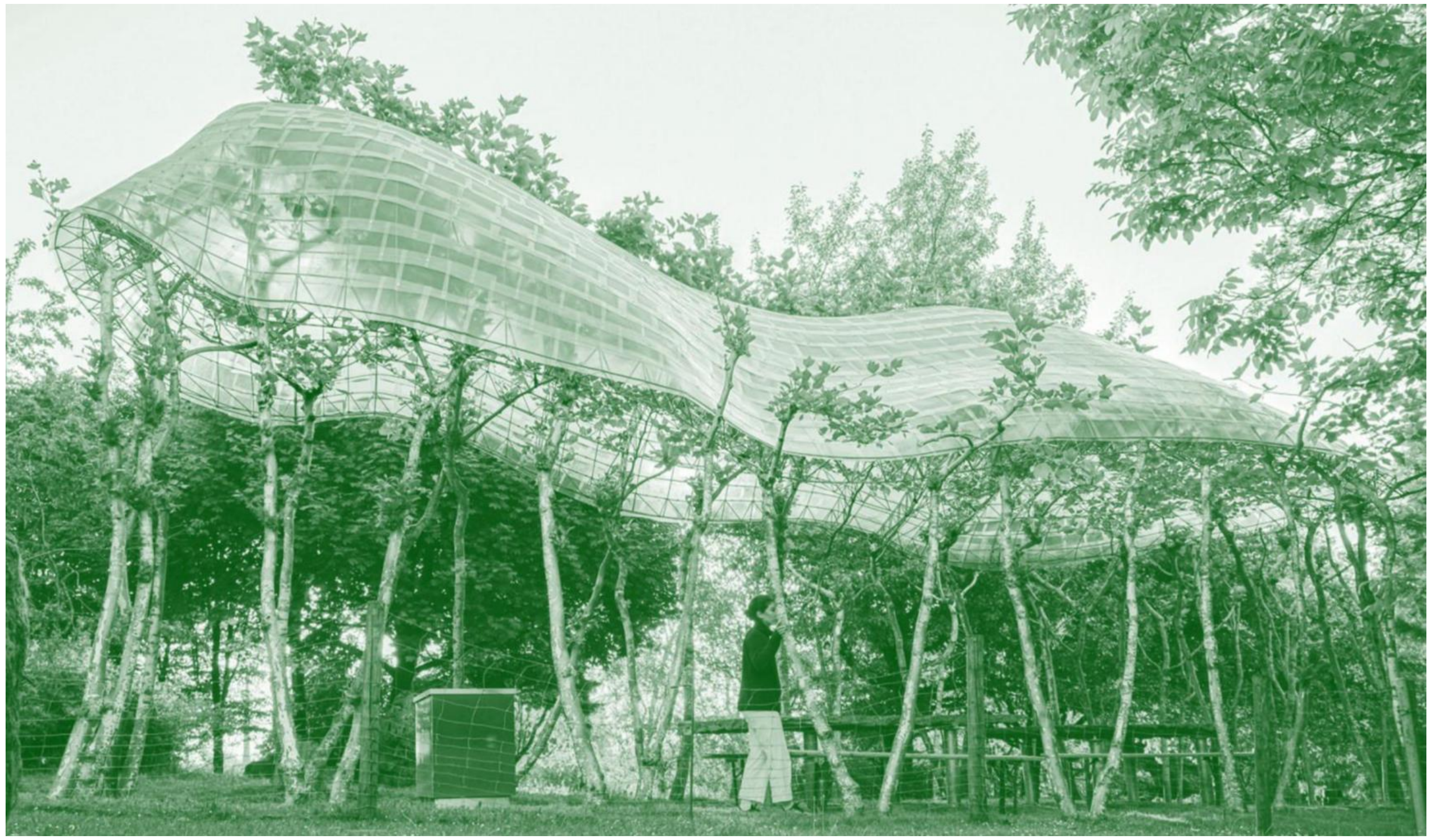
Introduction

Introduction

In our long-standing tradition to reimagine and reinterpret the relationship between architecture and nature, a new and exciting building approach has emerged known as *Baubotanik* - a German term that translates to *build* and *botany* (Ludwig, 2023).

Combining aspects of architecture, landscape and structural design, it presents an interesting challenge in current architectural practice by using living trees as a building material to form living structures. But what can you actually do with it? What forms can it take? What are its potentials and limitations?

This research project aims to take a closer look at these intriguing questions.



▲ **2** Recent structural experiment: Arbor Kitchen, Germany (Ludwig, 2023)

Introduction

Inspired by the vernacular living root bridges in India (Fig. 1) and building on the work of predecessors in related fields (Ludwig, 2023), Baubotanik is now being investigated rigorously as an architectural and construction method at the Technical University of Munich, Germany.

When it comes to available knowledge, Baubotanik is a relatively new building approach. It is not very established, it is still at the early stages, and it is very experimental. In recent years, there has been a lot of progress in the structural and technical research side of things (Figs. 2 & 3) (Ludwig, 2023). But less explored is the viability and design applications of this approach both in architecture and in the urban context. This will be the focus of this research paper, with the following research questions defining the scope of investigation: '**What can Baubotanik do?'** and **'What do spaces need?'**. The points of focus are, thus, **trees** and **space**.

3 Recent structural experiment: Baubotanik Tower, Germany (own photo)

02

METHOD

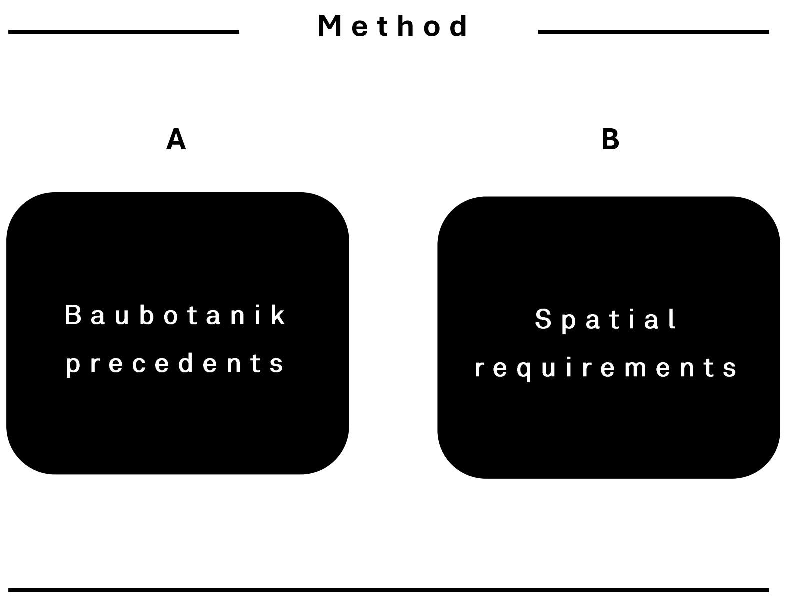
Method

Method overview

The method involves, on the one hand, analysing **Baubotanik precedents**, and on the other, analysing **spatial requirements**.

This analysis is conducted across 2 different climate zones – **tropical** and **temperate** – to see if there are any similarities or differences in the results. Specifically, it looks at the tropical monsoon and the temperate oceanic subcategories.

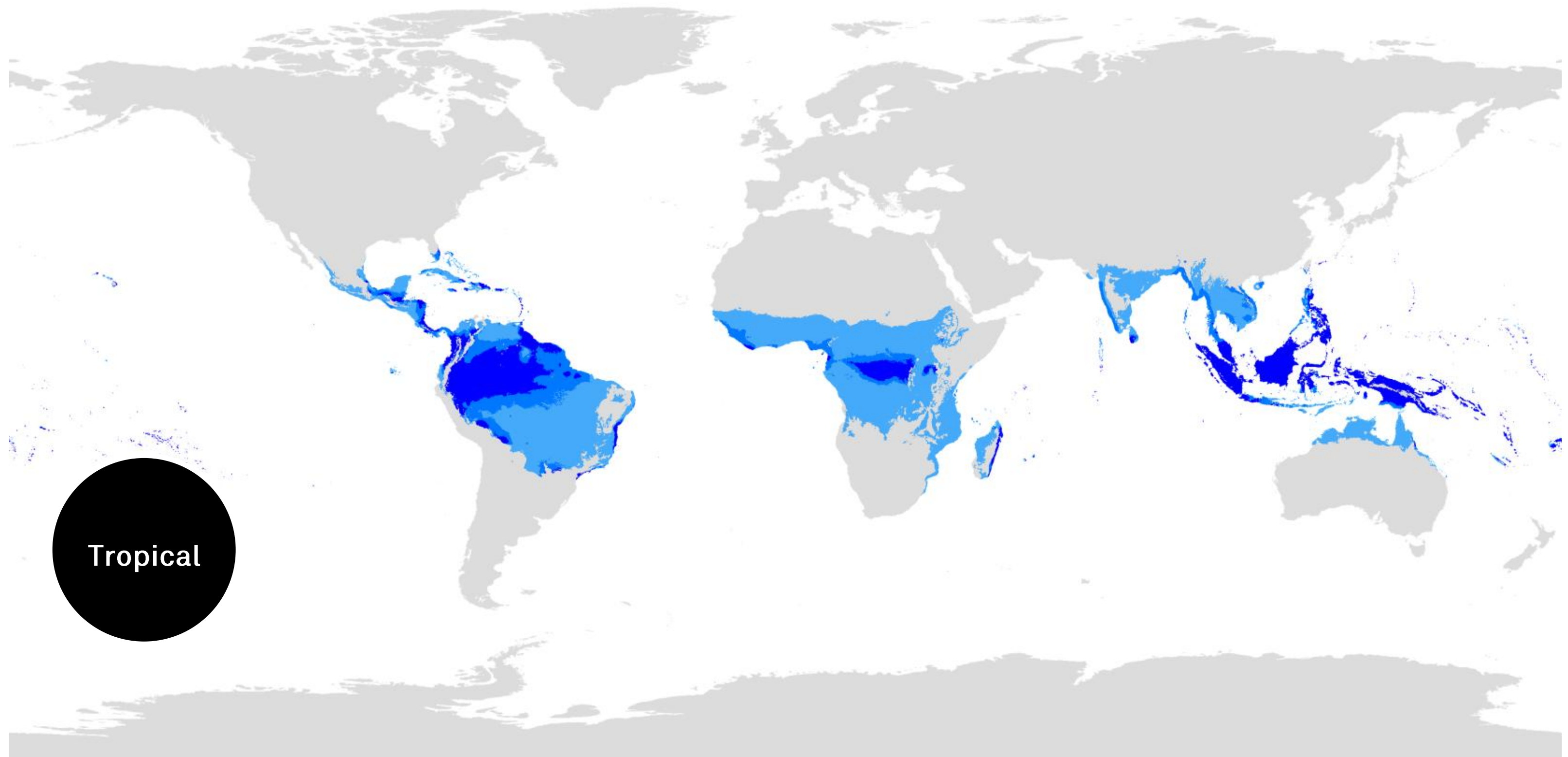
On the following pages, the analysis is explained in more detail.

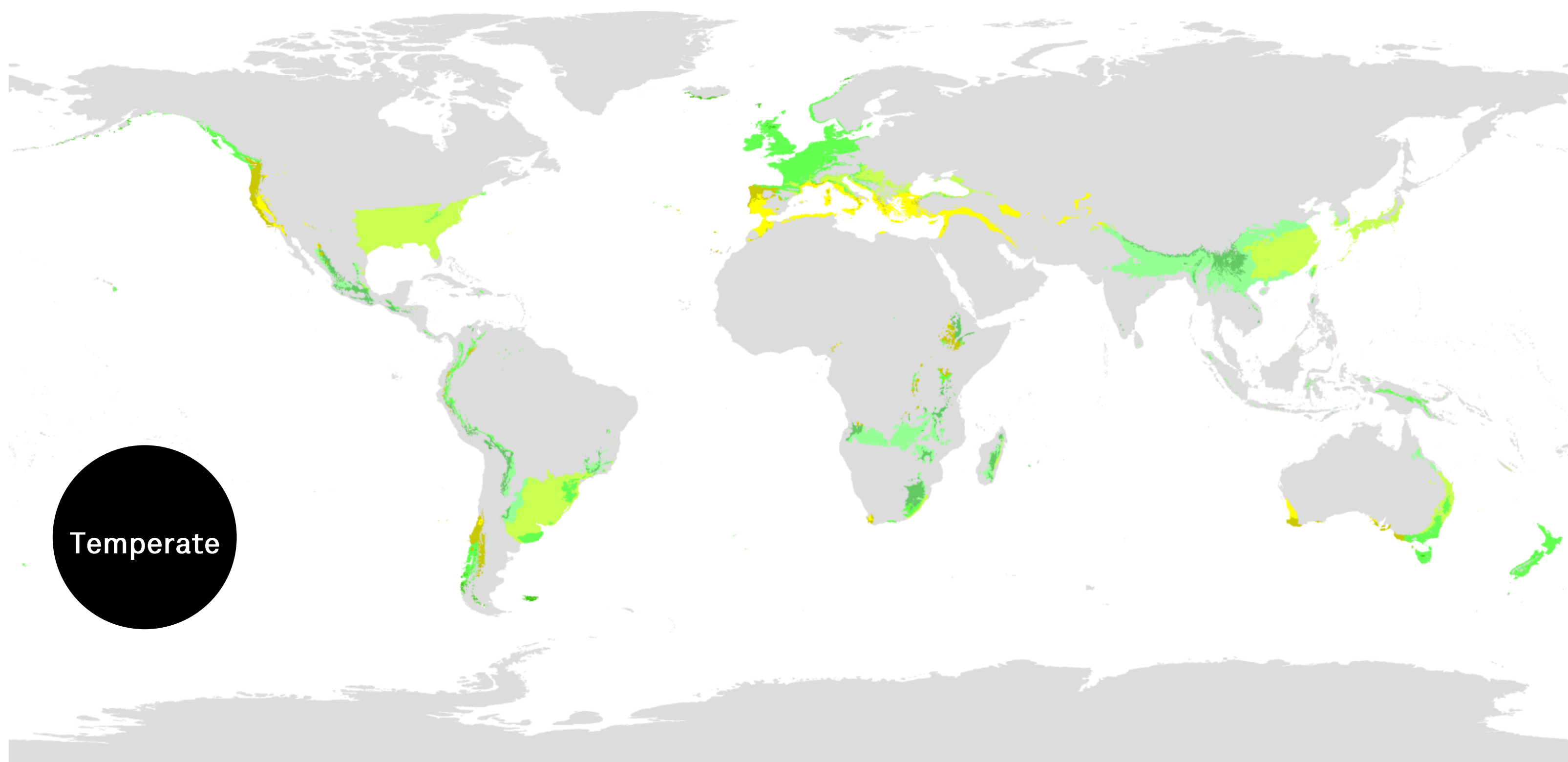


1a Method diagram ▲

1b Tropical climate map [1] ▶

1c Temperate climate map [2] ▶





[1] (Beck et al. 2023)

[2] (Beck et al. 2023)

Method

Baubotanik precedents

In total, **12 Baubotanik precedents** have been analysed: 6 in the tropical climate and 6 in the temperate climate. Unbuilt projects have not been considered. During the selection, projects with a minimum degree of load-bearing potential were favoured.

For each precedent, key aspects that were studied include spatial use, form and growth behaviour, at different points in time. Several site visits were conducted in 2024 to collect data of the temperate precedents.

Temperate climate:

1 Plane Tree Cube, Germany

2 Baubotanik Footbridge, Germany

3 Waldkirchen Birdwatching Station, Germany

4 Steveraue Platform, Germany

5 Baubotanik Tower, Germany

6 Arbor Kitchen, Germany

Tropical climate:

7 Living Root Bridges, India

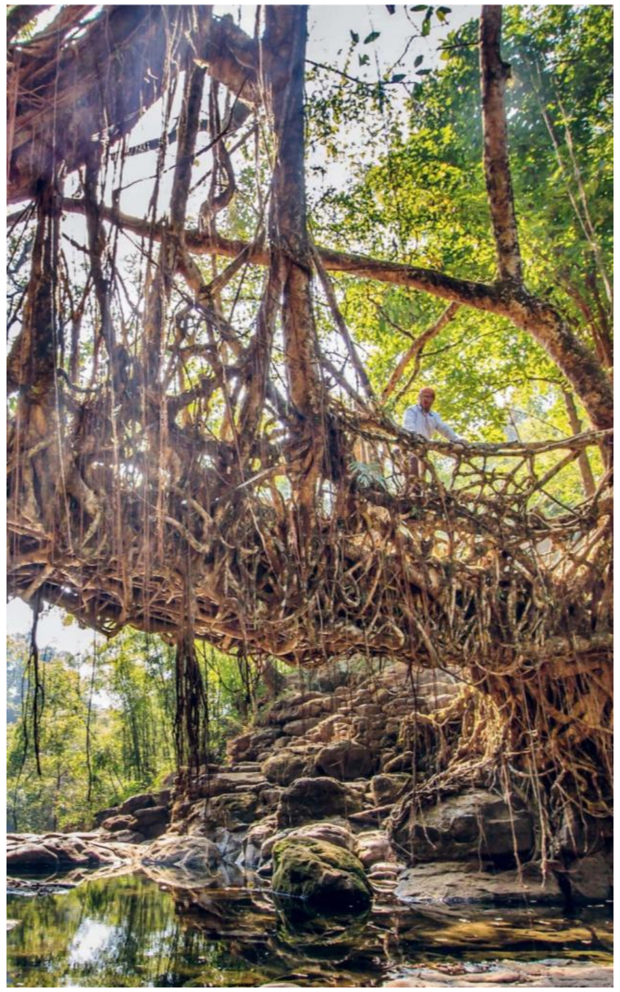
8 The Great Banyan, India

9 Sri Nambunayaki Amman Temple, India

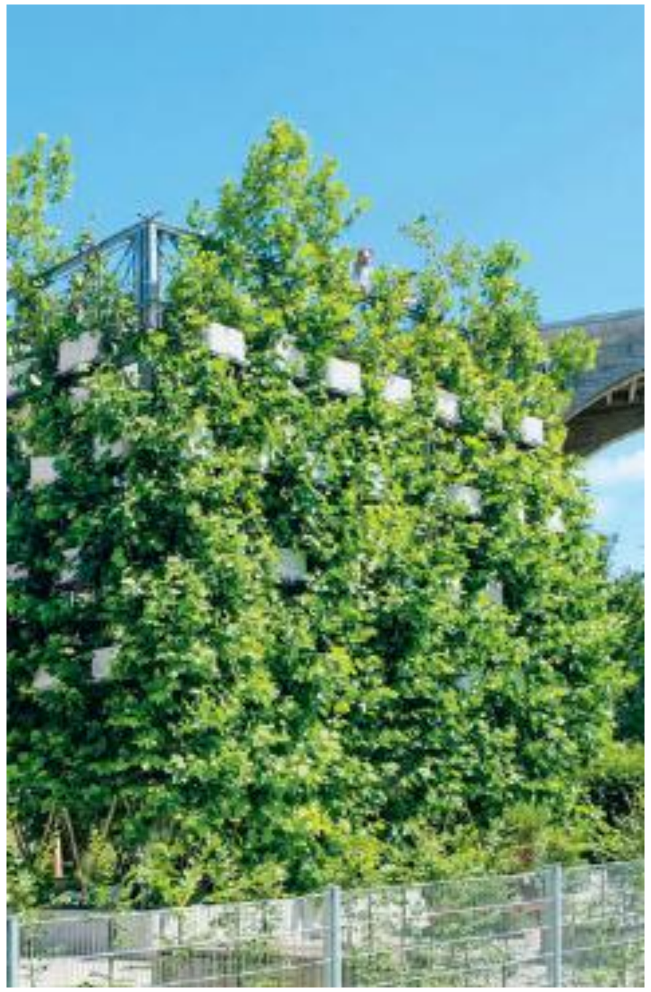
10 The Anping Tree House, Taiwan

11 Stone Wall Trees, China

12 Kam Tin Tree House, China



7 Living-root bridge, India (Tropical)[7]

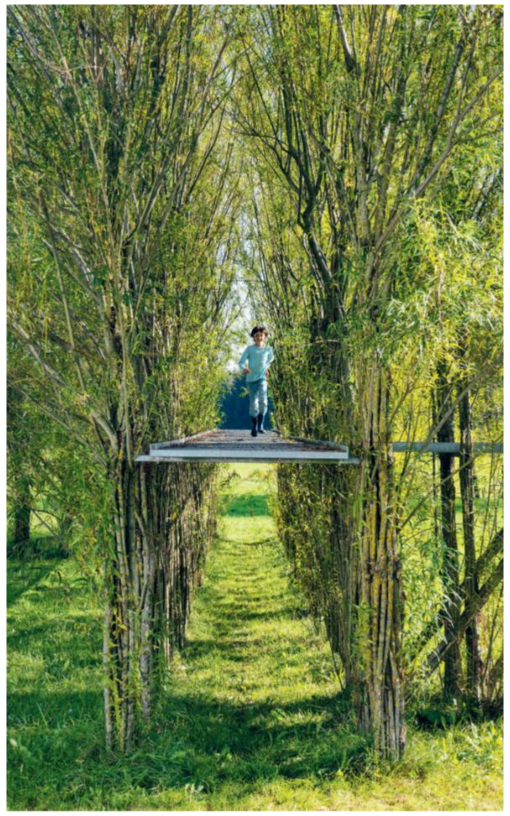


1 Plane Tree Cube, Germany (Temperate)[1]

[1] (Ludwig, 2023)
[2] (Ludwig, 2023)
[3] (O-L-A, n.d.)
[4] (O-L-A, n.d.)
[5] (Ludwig, 2023)
[6] (Ludwig, 2023)
[7] (Ludwig, 2023)
[8] (Savage, 2017)
[9] (Google Maps, n.d.)
[10] (Hoechuah, 2020)
[11] (DeWolf, 2016)
[12] (Greening, Landscape and Tree Management Section, n.d.)

Method

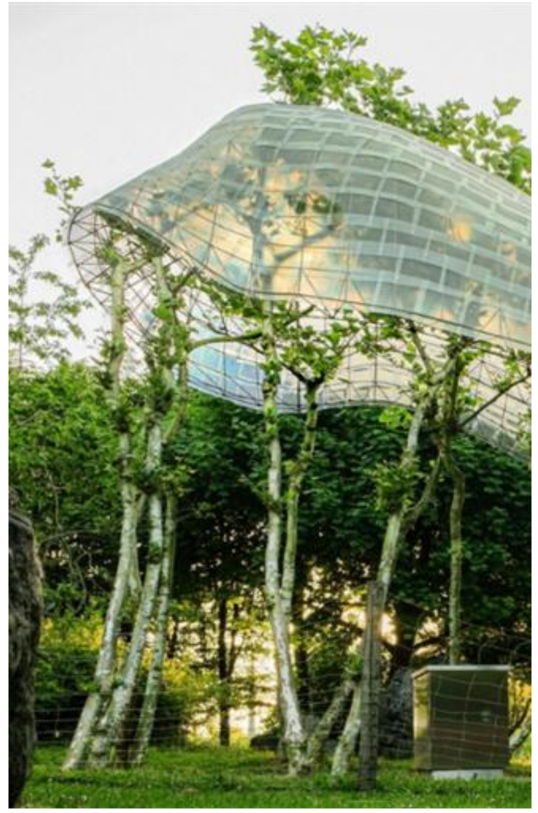
Temperate


2 Baubotanik Footbridge[2]

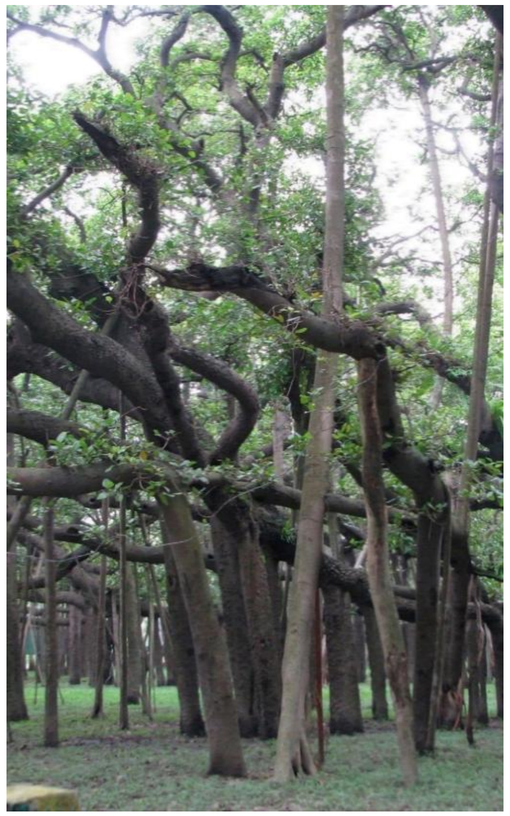

3 Waldkirchen Birdwatching Station[3]


4 Steveraue Platform[4]

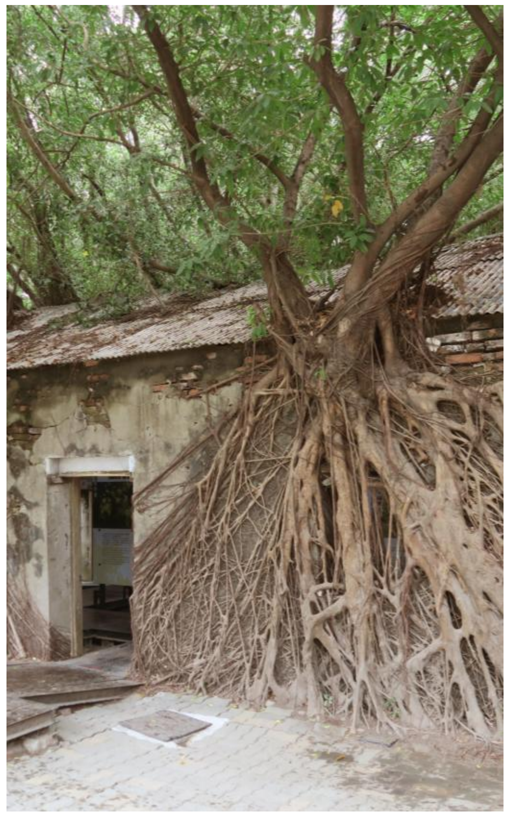

5 Baubotanik Tower[5]

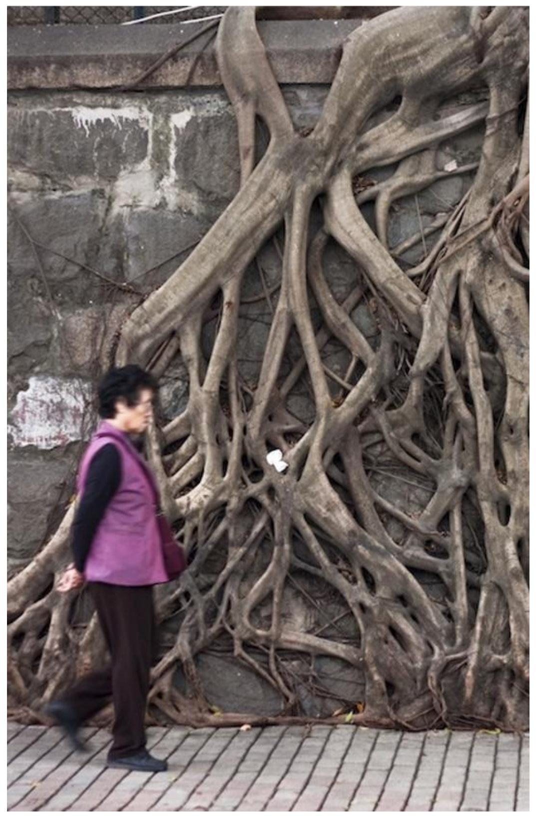

6 Arbor Kitchen[6]

Tropical


8 The Great Banyan[8]


9 Sri Nambunayaki Amman Temple[9]


10 The Anping Tree House[10]


11 Stone Wall Trees[11]


12 Kam Tin Tree House[12]

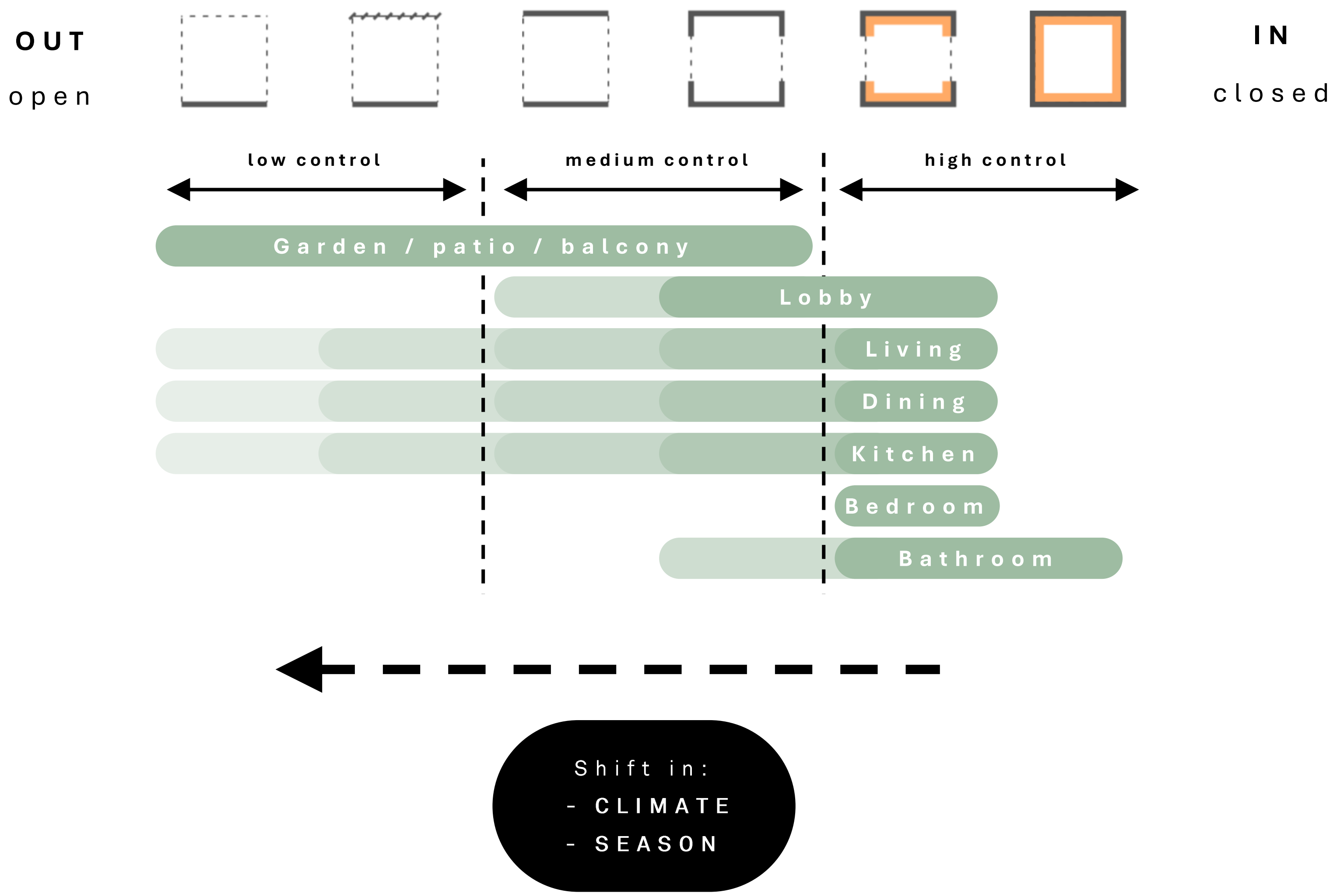
Method

Spatial requirements

In total, spatial requirements for over 50 spaces were analysed using the gradient in Fig. 13, with particular focus on spatial openness and climate control.

Each space was analysed across 2 climates – tropical and temperate – and across seasonal extremes. The aim being to see how spatial requirements change.

What we see is a shift in requirements, both across climates but also across seasons. Generally speaking, from temperate to tropical there is a shift towards less control. And, equally, from winter to summer, or from wet to dry season, there is also a shift towards less control.



13 The diagram shows typical rooms for a house in the temperate climate. These were analysed in terms of spatial openness and climate control at seasonal extremes, using the gradient shown. The analysis revealed a shift in spatial requirements.

03

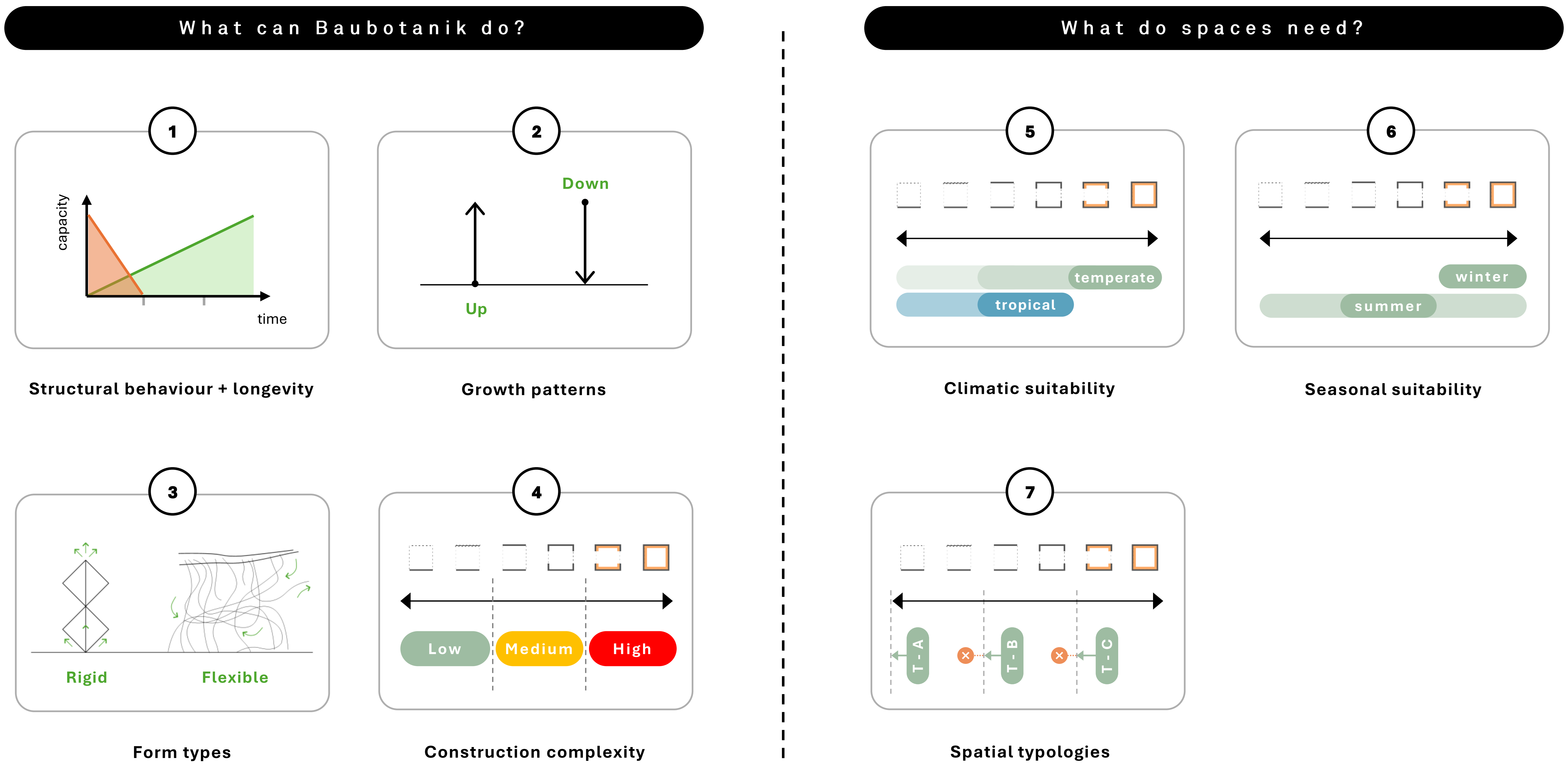
RESULTS

Results

Results overview

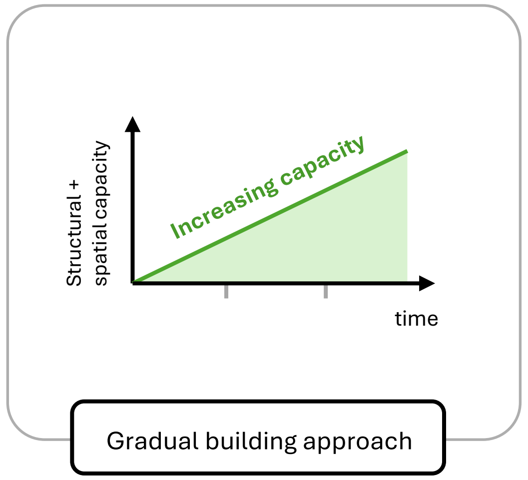
For the initial two questions, the results are **7 design considerations** that will serve as advice for designers, each covering a different topic. These are grouped by research question: Considerations 1-4 are in response to '*What can Baubotanik do?*', while 5-7 address '*What do spaces need?*'.

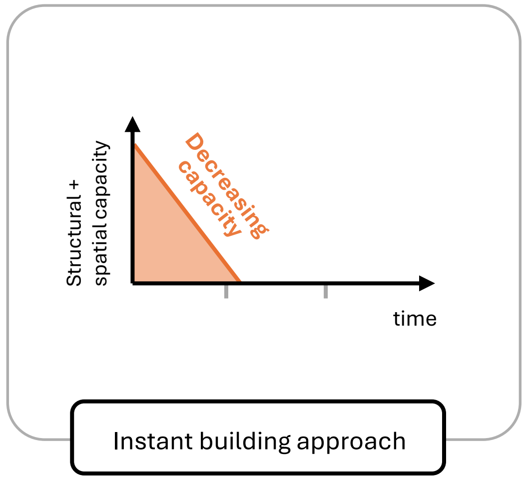
For each item, the paper will outline key observations and explain what this means for design. This should help designers assess where, when and how to use Baubotanik in a project.



1 Structural behaviour and longevity

Baubotanik structures exhibit one of two fundamental behaviours regarding their structural and spatial performance: an **increasing capacity** or a **decreasing capacity**. This is determined by the chosen building approach – **gradual** or **instant** – irrespective of tree species or geographic location.





Argument / supporting data:

Projects with an **increasing capacity** are the result of a **gradual building approach**. Here, both the structural output and spatial output are low at the start, but steadily increase with time. As living parts grow stronger, they can take on more load and, equally, the amount of space they can host increases (Ludwig, 2023). This approach ensures that the stresses imposed on the trees – fluctuations in light, spatial constraints, available energy or wound damage – are distributed over an extended period, allowing the living parts to adapt and recover from such stresses. The Living Root Bridge is a good example of this gradual but durable result, with the potential to last several centuries (see Timeline 1).

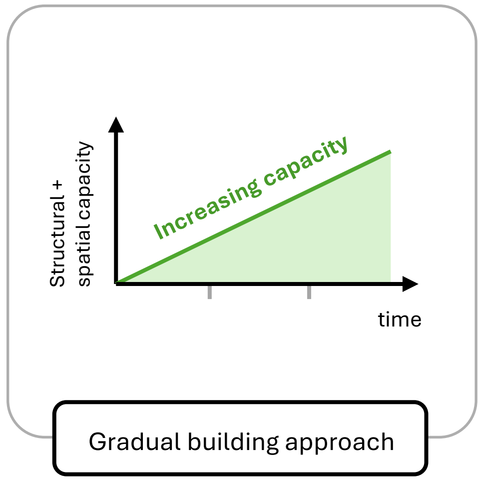
In contrast, a **decreasing capacity** is found in structures that employ an **instant building approach.** Here, the structural output and spatial output are high at the start, but rapidly decrease with time. This can be attributed to overexertion: initially, in order to reach the maximum output instantly, the trees get overexerted with multiple simultaneous stresses – limited light, overcrowding, energy depletion, wounding and fungal exposure – pushing the trees past their biological limits (Ludwig, 2023). As seen in the Waldkirchen Birdwatching Station (see Timeline 2), such structures rarely last more than a few years.

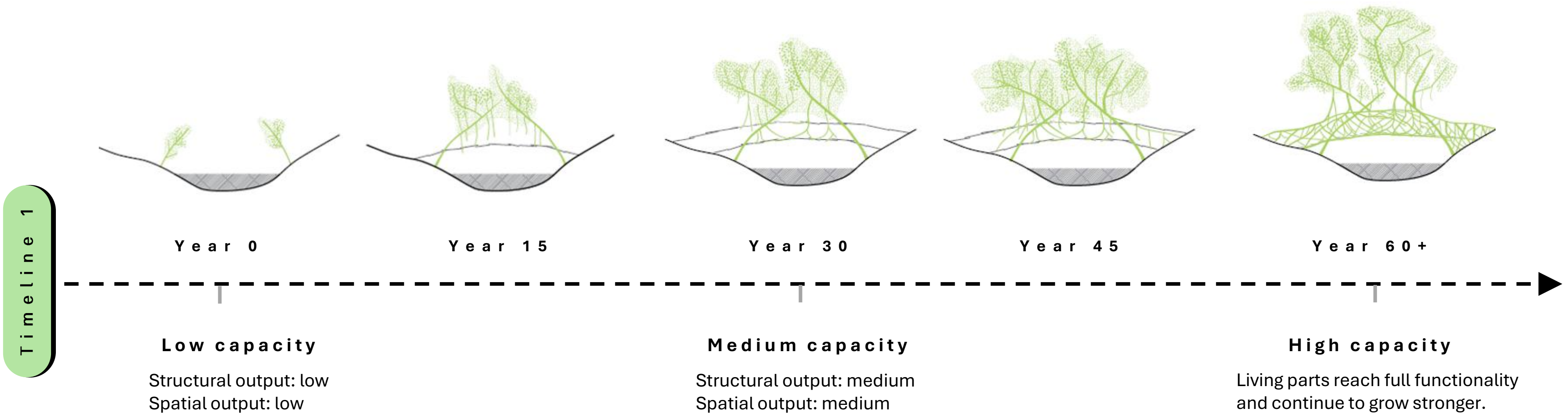
What does this mean for design?

A **gradual building approach** ensures an increasing structural and spatial capacity with durable results**,** thus making it suitable for long-term or permanent projects. Here, the results are slow but, in return, you can expect a long-lasting structure.

An **instant building approach** guarantees immediate functionality at the cost of lifespan, thus making it useful for short-term or temporary projects, such as pavilions or spatial installations, where instant results are essential and a short lifespan is expected or even desired.

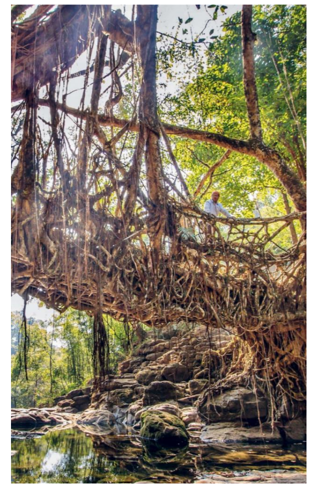
These two opposing strategies suggest that recognising the close relationship between construction speed**,** project performance, and longevity is essential for the design of a baubotanical structure. Thus, identifying a project's temporal needs early on is imperative, in order to find the right balance and ensure that the resulting structure behaves and develops as expected.





▲

Timeline 1: Long lifespan. Living Root Bridge transitions from **low output** to **high output** over the course of decades. Living parts grow stronger with time, ensuring a steady increase in the overall structural and spatial capacity of the bridge. Timeline adapted from Ludwig (2023).



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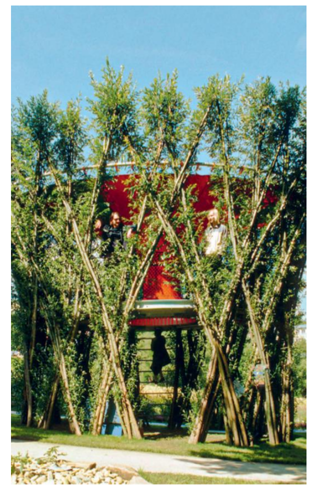
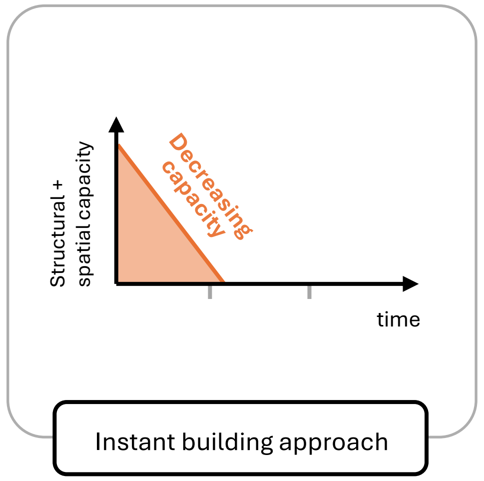
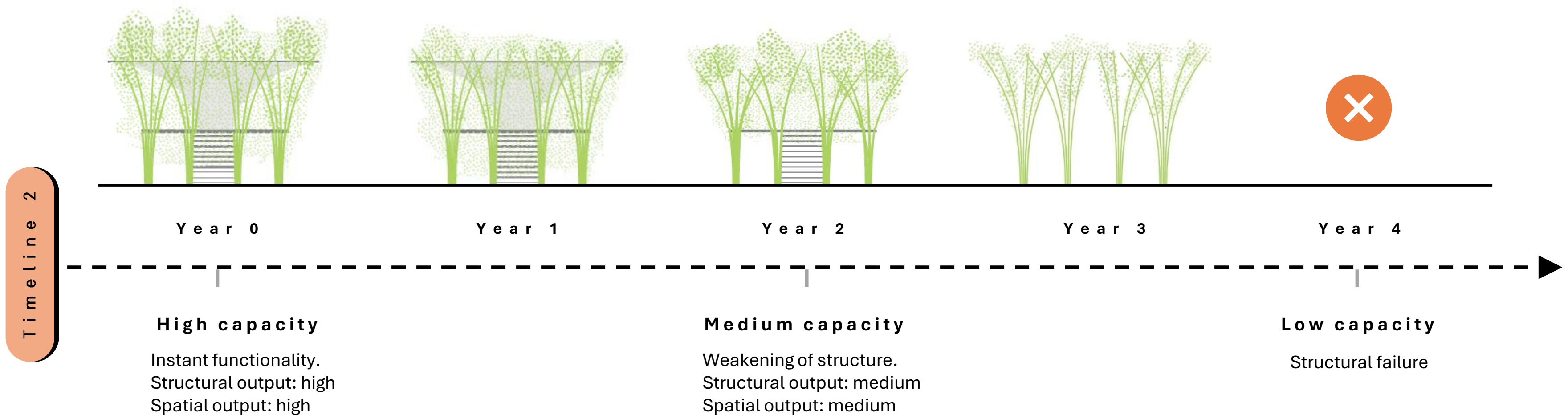
3a Living Root Bridge. High capacity reached in **Year 60**. Approx. Year 200 in image.[1]

3b Waldkirchen Bird-watching Station. High capacity reached in **Year 0**.[2]

▼







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Timeline 2: Short lifespan. Waldkirchen Birdwatching Station goes from **high output** to **low output** in just a few years. Living parts get weaker rapidly, eventually leading to structural failure. Timeline adapted from Ludwig (2023).

▲

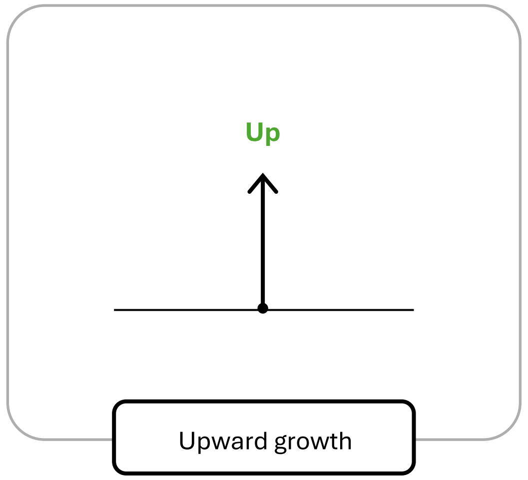
3a & 3b Timescale comparison: high capacity reached at different points in time.

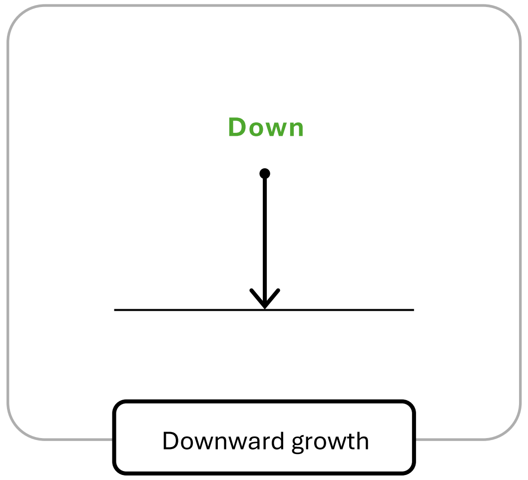
[1] (Ludwig, 2023)
[2] (O-L-A, n.d.)

2 Growth patterns

Living structures exhibit two distinct growth patterns: dominant **upward growth** or dominant **downward growth**.

This is determined by the **tree species** and their inherent **growth strategy**, regardless of any human or environmental interference.





Argument / supporting data:

Upward growth is found in temperate precedents using soil-rooted species. These typically feature a compact trunk system with a single anchorage point to the ground, resulting in limited structural elements at lower level for baubotanical structures. To compensate, temperate structures like the Plane Tree Cube employ multiple trees to increase the number of construction elements, improve load-distribution and extend the horizontal reach at ground level (see Figs. 2a & 2b).

In contrast, **downward growth** is typical of tropical precedents with aerial-rooted species. A single tree can generate numerous aerial roots radially, providing multiple structural elements at lower level and a broad horizontal span without requiring additional trees, as observed in The Great Banyan in India (see Figs. 2c & 2d).

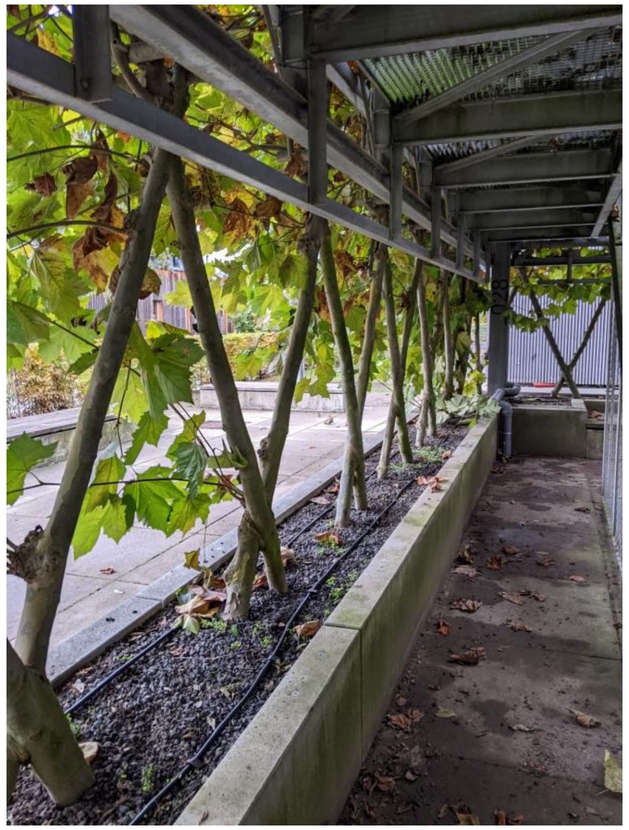
What does this mean for design?

Upward systems: Multiple trees are required to create a single small-to-medium scale living structure.

- **Advantages**: Relatively predictable form due to fixed initial anchor points and low horizontal expansion.
- **Challenges**: Significant tree competition – light, space, nutrients – due to high tree density. Spatial planning is key at the initial stage to reduce this, combined with long-term management focusing on pruning and spacing strategies.

Downward systems: A single tree is sufficient to create a small-to-medium scale living structure.

- **Advantages**: There is no inter-tree competition, since a single tree forms the entire structure.
- **Challenges**: The origin point of aerial roots along a branch is less predictable. However, their anchorage point to the ground as well as the entire path can be trained.



2b Each grid-point is comprised of two individual trunks that have fused over time. This doubles the available construction elements. (own photo)

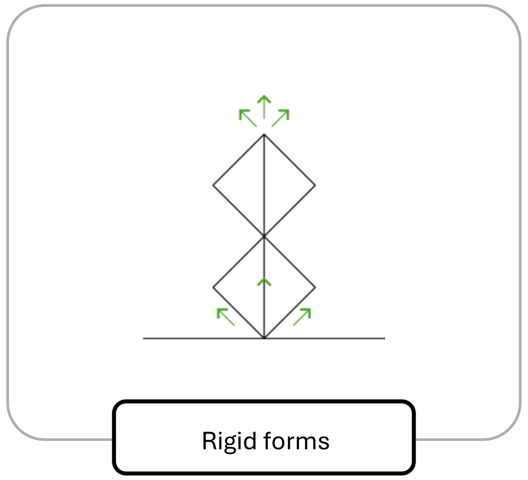
2a In order to have sufficient construction elements to cover an area of 10m x 10m, the Plan Tree Cube employs 58 pairs of upward-growth trees at ground level, totalling 116. The image shows a row of fused pairs on the southern façade at ground level. (own photo)

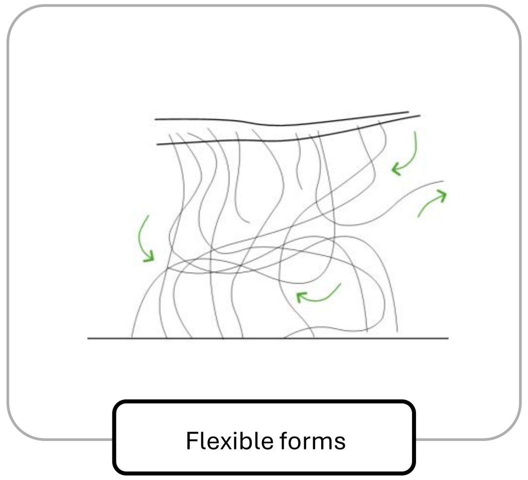
2c The Great Banyan is composed of a single tree that covers 18,000m^2 (Botanical Survey of India, n.d.), thanks to the downward growth pattern of its aerial roots, which act as supports or secondary trunks. (Rahul, 2015)

2d Image of the southeastern entry to The Great Banyan gives an indication of its vastness. (Third Eye Traveller, 2016)

3 Form types

Living structures can be categorised into two types of forms based on spatial and structural malleability: **rigid forms** and **flexible forms.** This distinction is determined by the **tree species.**





Argument / supporting data:

Rigid forms employ soil-rooted tree species. While **branches** and **trunks** serve as viable construction elements, underground roots do not. The available components have relatively **low malleability** and can only be guided within a **narrow range** (approximately 0–45°) from their natural growth direction. A defining feature of these projects is the predominance of vertical and/or diagonal living elements, often at regular intervals, but a lack of horizontal load-bearing components, instead achieved by technical elements. Temperate precedents like the Baubotanik Footbridge (Fig. 3a) are a prime example of this.

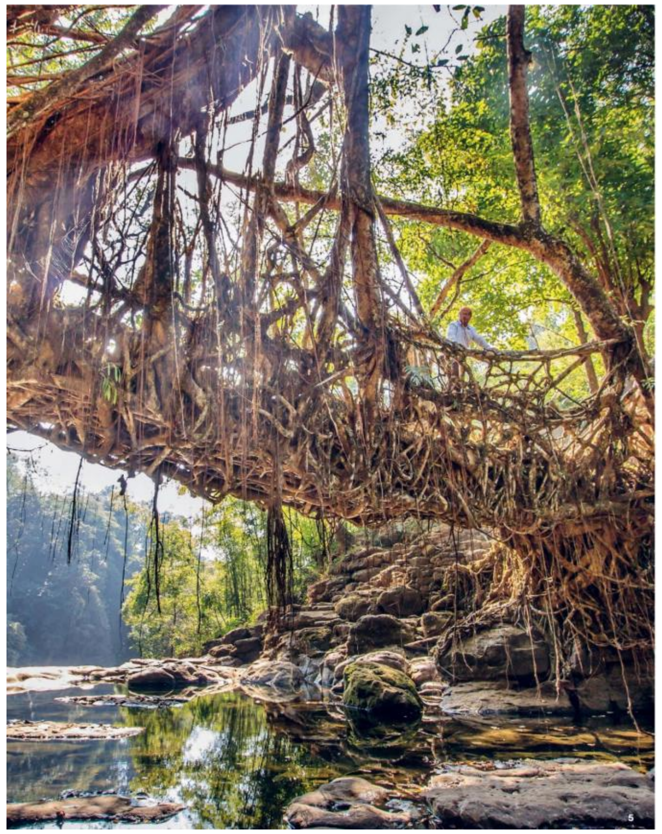
In contrast, **flexible forms** employ aerial-rooted tree species. These structures incorporate not only branches and trunks (low malleability), but also **highly malleable aerial roots** as construction elements (Fig. 3c). These have a **wide directional range**, meaning they can be trained in virtually any direction. In low-trained structures, these are relatively vertical due to gravity. In highly trained structures, these are found in every imaginable direction, often forming highly intricate networks. Such forms are typical in tropical precedents, such as the Wah Thyllong Living Root Bridge in India (Fig. 3b & 3c).

What does this mean for design?

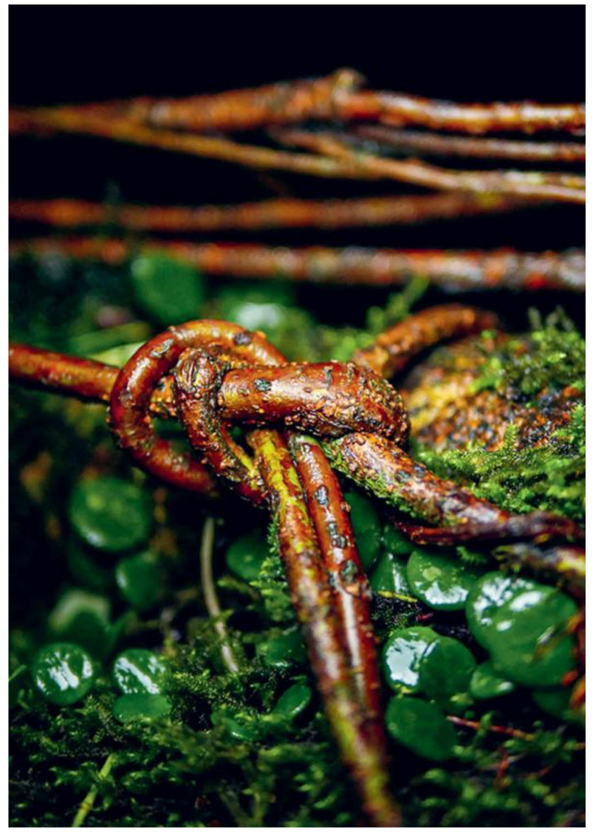
These findings underscore the critical role of species selection in the structural and spatial potential of living architectural forms. The use of soil-rooted species restricts achievable shapes to predominantly **orthogonal** and **geometric** forms, lending structures a strong and legible vertical rhythm. In contrast, aerial-rooted species allow greater design freedom and the creation of more **intricate** and **diverse** geometries, resulting in a naturally more **organic** visual language.

3

3a The living elements in the Baubotanik Footbridge are predominantly **vertical** with a few **diagonals**. Notice how the diagonals have been planted obliquely instead of attempting to bend them into shape. This speaks to the low malleability of soil-rooted species. As seen here, the baubotanical forms arising from such elements are, thus, quite rhythmic and orthogonal. Also noteworthy is the lack of **living horizontal** components. The elevated horizontal walkway is comprised of steel gratings that are fixed to the trees. (Ludwig, 2023)



3b The Wah Thyllong Living Root Bridge is made up of countless aerial roots trained into the shape of a load-bearing structure. The wide directional range of these components is evident in this image, thus, creating more flexible geometries. (Ludwig, 2023)

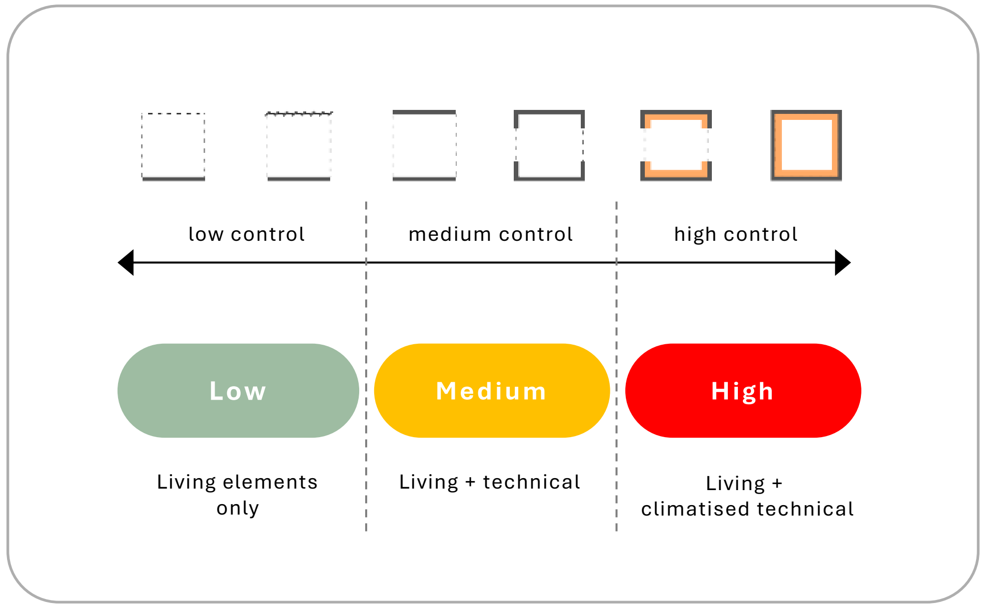


3c This image shows how pliable young aerial roots can be, which can be trained in virtually any direction or shape, in this case, a knot that forms part of a larger lattice-like root network. As they mature, they gain in strength and rigidity. (Ludwig, 2023)

4 Construction complexity

For Baubotanik projects, **construction complexity** can be classified into 3 groups: **low, medium** and **high**.

It is directly proportional to the level of environmental control required in a given space: as control requirements increase, so does the need for technical interventions, hybridisation, and precision in integrating living and technical systems.



Argument / supporting data:

1. Low-control space → Low complexity

Low-control spaces can be constructed with **living elements alone**. Here, primary structure and non-solid spatial divisions are formed using trunks, branches, aerial roots or foliage, without the need for technical components. This is observed across both temperate and tropical climates, for instance in the Sri Nambunayaki Amman Temple (Fig. 4a).

2. Medium-control space → Medium complexity

Medium-control spaces require one or more **solid divisions**, like a roof or a wall. Since these cannot be built using living elements alone, technical additions are introduced. This results in a **hybrid structure**, where **living and technical** elements are combined. Such structures demand increased coordination between living and technical systems. As seen in the Arbor Kitchen (Fig. 4b), hybrid systems are feasible across both temperate and tropical climates.

3. High- control space → High complexity

High-control spaces are yet to be built with current Baubotanik techniques. To meet the stricter environmental demands and given the obvious limitations of a living material, a **hybrid structure** that integrates more complex **climatised technical elements** is necessary. Theoretically, an exo-skeletal, living structure could host small, climatised enclosures within its framework. The biggest challenge would be ensuring an airtight envelope while also building a structurally sound interface between the technical enclosure and the living structure itself. Several speculative projects have attempted to address this (Fig. 4c), but whether it is truly possible in practice remains to be seen.

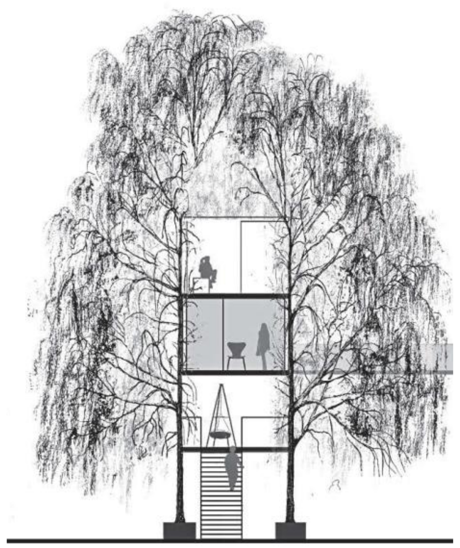
What does this mean for design?

- **Hybridisation:** Hybrid design considerably expands Baubotanik's architectural viability and spatial range well into the medium-control zone, through its ability to combine living and technical systems.
- **Spatial compatibility**: From a construction perspective, the Baubotanik approach is inherently more suited to spaces in the low- to medium-control range, where flexibility in spatial openness and climate control is acceptable or even desirable. Given the uncertainties around high-control spaces, resorting to conventional construction for such spaces might be necessary at this point in time – at least until more practical research has been conducted into this area.
- **Selective application**: This suggests the need to apply Baubotanik selectively in a project, by targeting specific parts of the programme: A fully living structure for low-control spaces, a hybrid structure for medium-control spaces and conventional construction for high-control spaces.

4a Low complexity. At Sri Nambunayaki Amman Temple, trunks, branches, aerial roots and foliage form an outdoor gathering space; one that requires low levels of environmental control. In this image, we see branches and trunks subdividing the space and framing secondary enclosures, clusters of aerial roots forming visual screens, and foliage creating a visual screen overhead. This type of low-control space is relatively easy to construct with Baubotanik. (Google Maps, n.d.)

4b (left) Medium complexity. Arbor Kitchen is a **hybrid structure** that combines trees and a solid roof to form a space sheltered from the rain (medium-control). The technical roof system, composed of polycarbonate shingles fixed onto a steel rebar sub-structure, is fully supported by the inward arching trees. Due to the need for increased coordination between living and technical elements, the construction complexity in this project is medium. (Ludwig, 2023)

4c (right) Connection point. Interface between living and technical components at eaves level (photo looking up at the tree, into the roof structure) . Several threaded rods drilled into the tree trunk enable further technical fixings to be attached, allowing the technical roof system to be installed. (own photo)

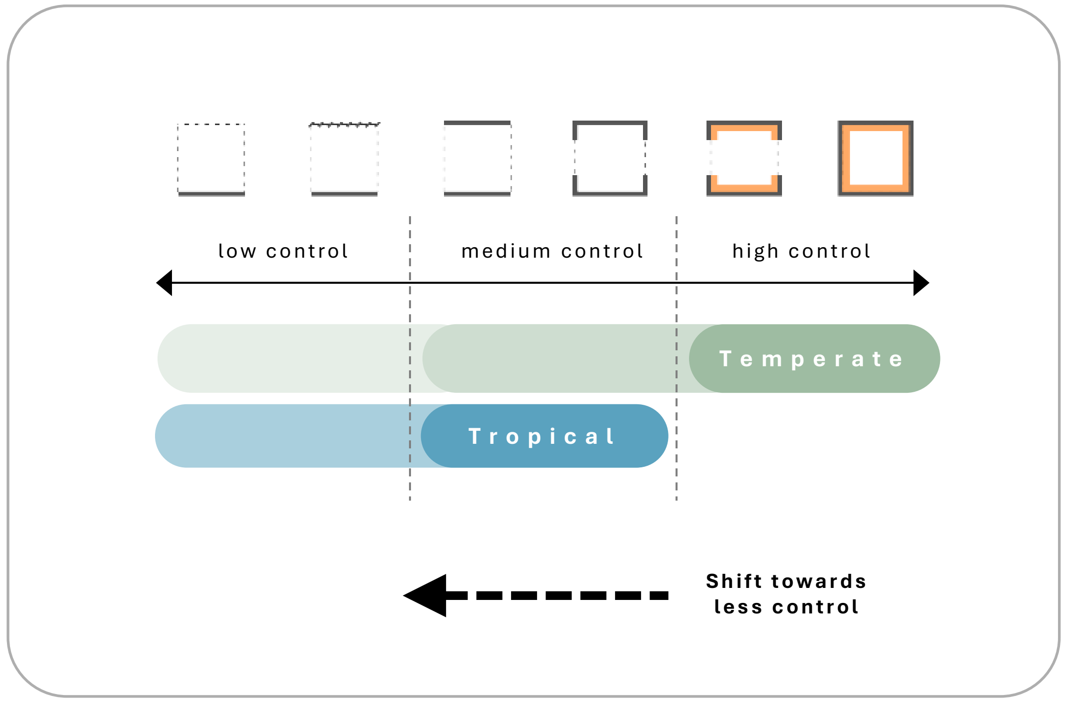


4c High complexity. Speculative project ‘Grow!’ by OLA creates small, contained cores within a load-bearing living structure (Ludwig, 2023). An interpretation of how a high-control space could work with Baubotanik. Left: (Ludwig, 2023). Right: (Ludwig, 2023)

5 Climatic suitability

Spatial requirements undergo a **shift across climate zones**. From temperate to tropical spaces, there is a shift towards lower degrees of environmental and spatial control.

5a Spatial requirements for each climate plotted against the environmental control gradient.



Argument / supporting data:

To assess the shift in spatial requirements on a comparable basis, we examine a generic living room across the temperate climate and the tropical climate.

Over the course of a year, a living room oscillates between **low** and **medium** control for tropical climates, and **low** and **high** control for temperate climates (Fig. 5b).

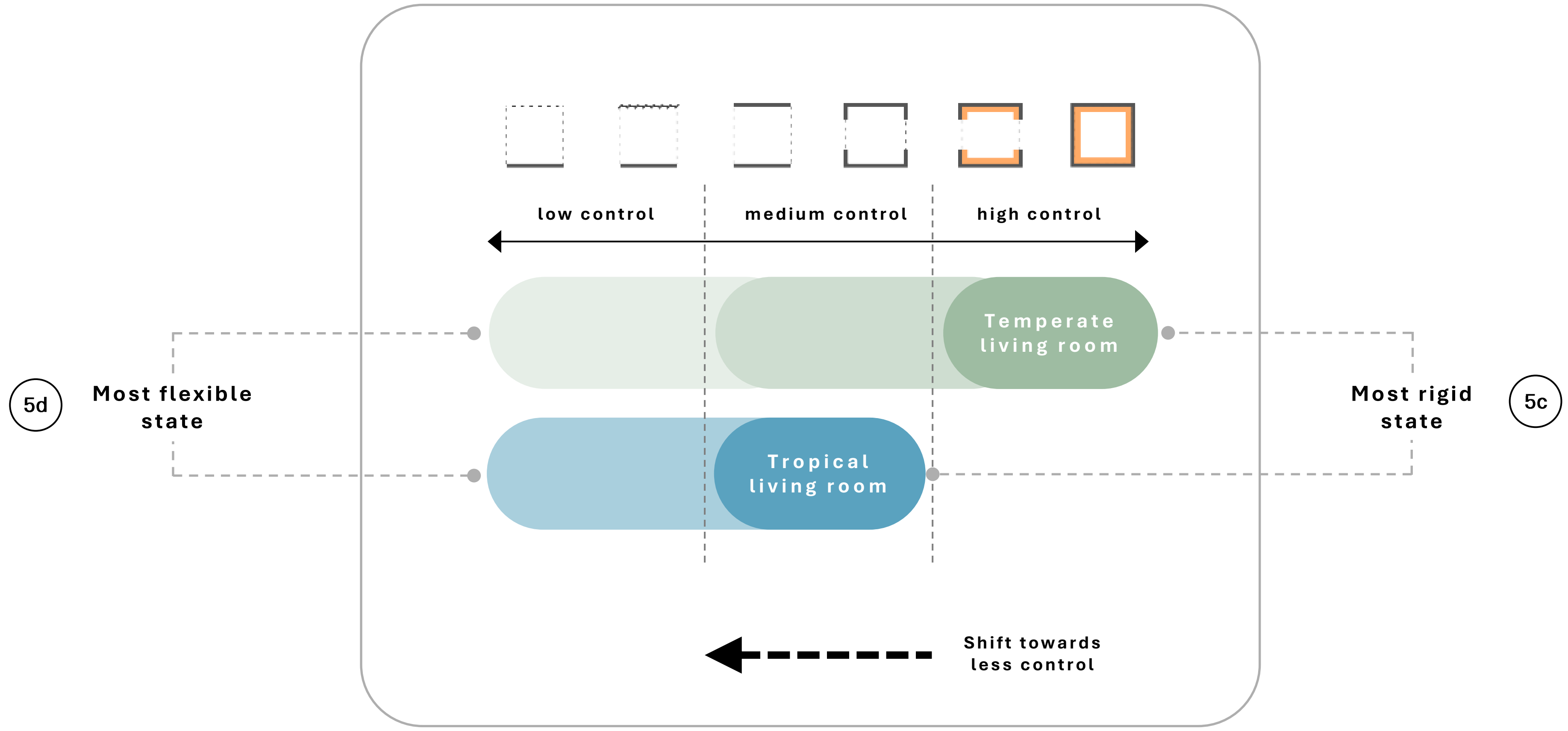
In its most **rigid state**, a living room in the temperate climate requires high control, while in the tropical climate, this position shifts to medium control (Fig. 5c).

In its most **flexible state**, while both climates are able to reach the low-control zone, tropical climates permit low-control states more frequently and for longer uninterrupted periods (Fig. 5d).

What does this mean for design?

The analysis highlights the importance of geographical location and climate zone in Baubotanik design to maximise compatibility and make full use of its potentials.

For a given space, **tropical environments** enable more relaxed spatial requirements year-round, encouraging open, outward-oriented spatial configurations. **Temperate spaces**, in contrast, present a significant design challenge for Baubotanik during the high-control period, necessitating sealed enclosures for significant parts of the year. Therefore, **Baubotanik systems** – benefiting from high permeability, adaptability, and integration with outdoor conditions – are particularly **well-suited to tropical climates,** allowing them to remain functional year-round.



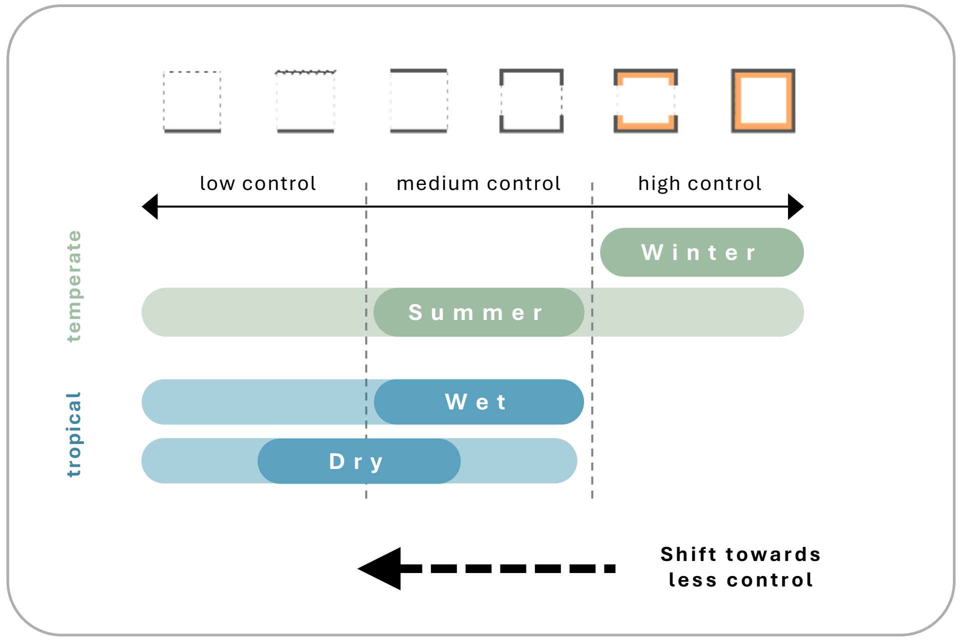
5b Climatic suitability: Tropical or Temperate?

In this diagram, the colour intensity represents the frequency of occurrence over the course of a year. The darker tone represents a more frequent state, with lighter tones representing less frequent occurrences.

Based on this, a temperate living room requires higher control for significant parts of the year. In contrast, the spatial requirements for a tropical living room are more relaxed year-round, making it better suited to the outdoor-oriented nature of Baubotanik design. In practical terms, this could mean that a Baubotanik living room in the temperate climate has limited year-round use, while in tropical climates, it is functional all year-round.

6 Seasonal suitability

Spatial requirements in temperate and tropical climates undergo a **shift across seasons**. From summer to winter and from wet to dry season, there is a general shift towards lower degrees of environmental and spatial control.



Argument / supporting data:

To assess the shift in spatial requirements on a comparable basis, we examine a generic dining room at seasonal extremes, for both climate zones.

Temperate oceanic climate: Seasonal shifts are pronounced, due to the strong fluctuation in temperature, rain, sun and wind.

In **winter**, a dining room consistently requires high levels of control (Fig 6b). The need for complete protection from the cold, wind, and rain dictates a fully enclosed, sealed interior space.

In **summer**, requirements oscillate between low and high control, with medium control often being the default state (Fig. 6c). Based on fluctuations in temperature or rain, requirements may shift to the low-control zone on a hot day, or back to the high-control zone on a cold night.

Tropical monsoon climate: Seasonal shifts in the tropical climate tend to be less extreme, thanks to year-round warm temperatures. Rain, in this case, is the primary driver for shifts.

During the **wet season**, the need for protection from the rain results in a generally medium-control state, with the potential for brief periods of lower control when the rain ceases (Fig. 6d).

In the **dry season**, protection from the rain is no longer a daily concern. As a base condition, a dining room will comfortably sit halfway between the low-control zone and the medium-control zone. Based on fluctuations in sun intensity or occasional rainstorms, requirements may shift to the bottom end of the low-control zone while sun intensity is low, or back to the far end of the medium-control zone during a rainstorm (Fig. 6e).

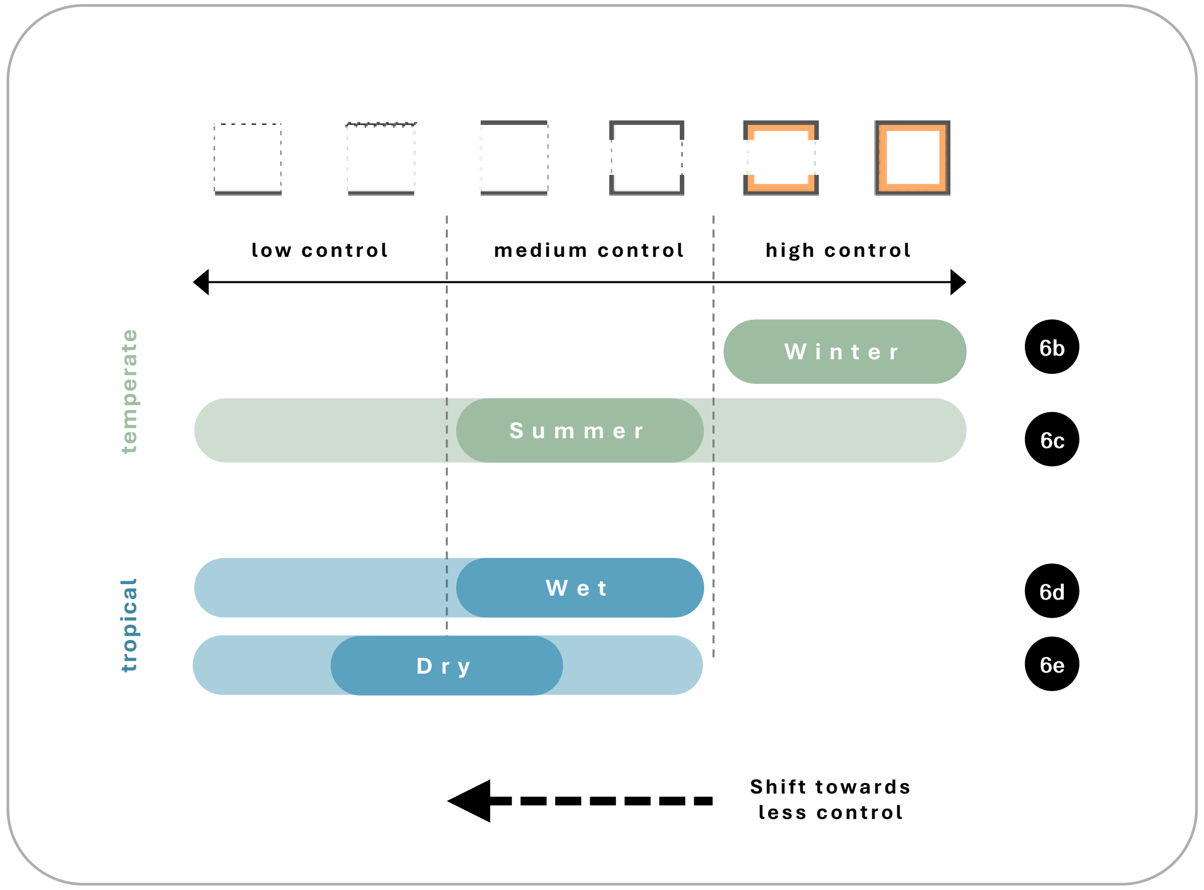
What does this mean for design?

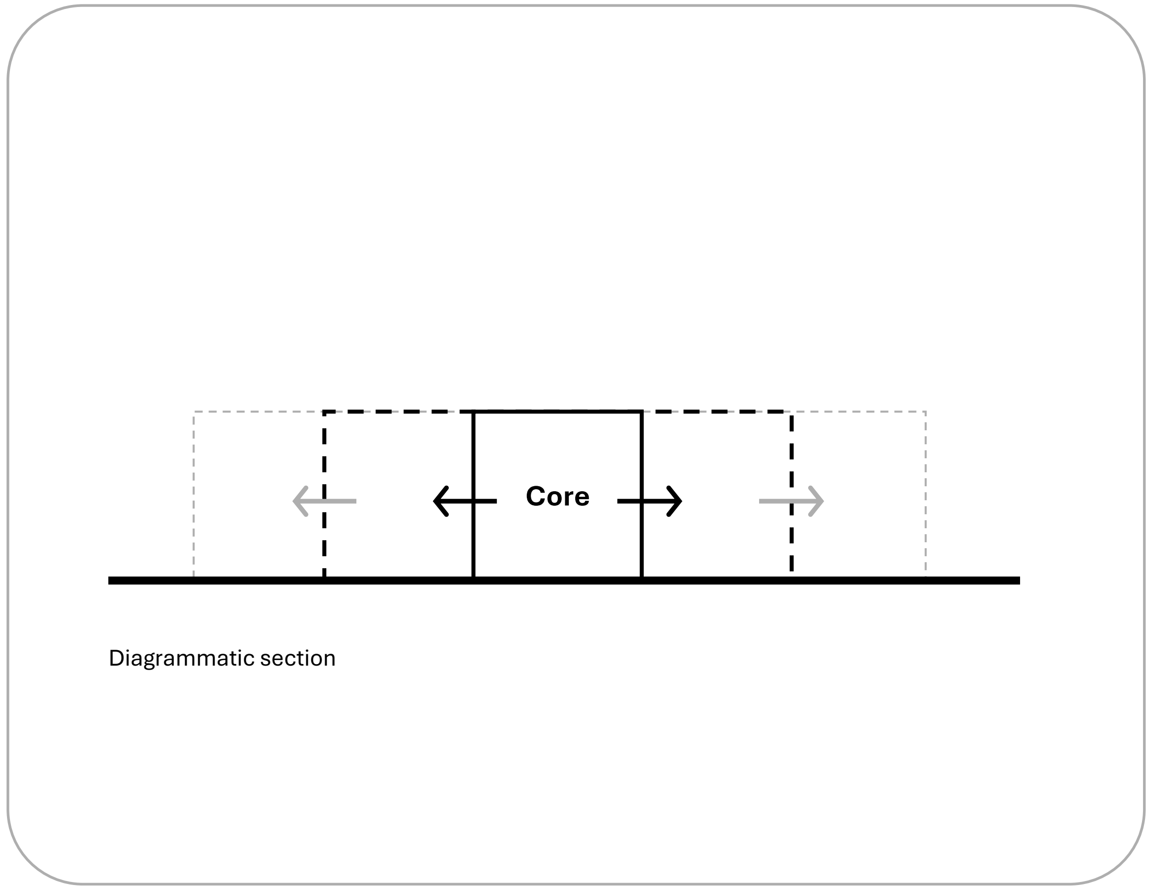
In each climate zone, the findings suggest that certain seasons are better aligned to Baubotanik needs and potentials:

Temperate climate: Winter or summer? Baubotanik systems are **more suitable** for the **summer** months, with winter months presenting a significant challenge, potentially leading to a limited annual use.

Tropical climate: Wet or dry season? While the dry season presents greater freedom for Baubotanik systems than the wet season, **both periods demonstrate good potential**. Overall, tropical climates offer high year-round compatibility with Baubotanik design.

Adaptability: Given the seasonal shift in spatial requirements, adaptability could be an important design principle for both climates. This could mean making small, controlled spaces and wider (semi-)outdoor spaces (lower control), resulting in a space with shifting boundaries that expands and contracts (Fig. 6f).





6a Seasonal shifts. This diagram plots the spatial requirements for a generic dining room in both the temperate climate (in green) and the tropical climate (in blue) at seasonal extremes. The darker tone represents the 'default' state, with lighter tones representing a temporary situation. From winter to summer and from wet to dry season, there is a shift towards less control.

- Default state
- Temporary state
- Default state
- Temporary state

6f Adaptability. As an architect, this shift across seasons allows room for play in spatial design. In this diagram, a small, controlled space can expand out onto wider (semi-)outdoor spaces.

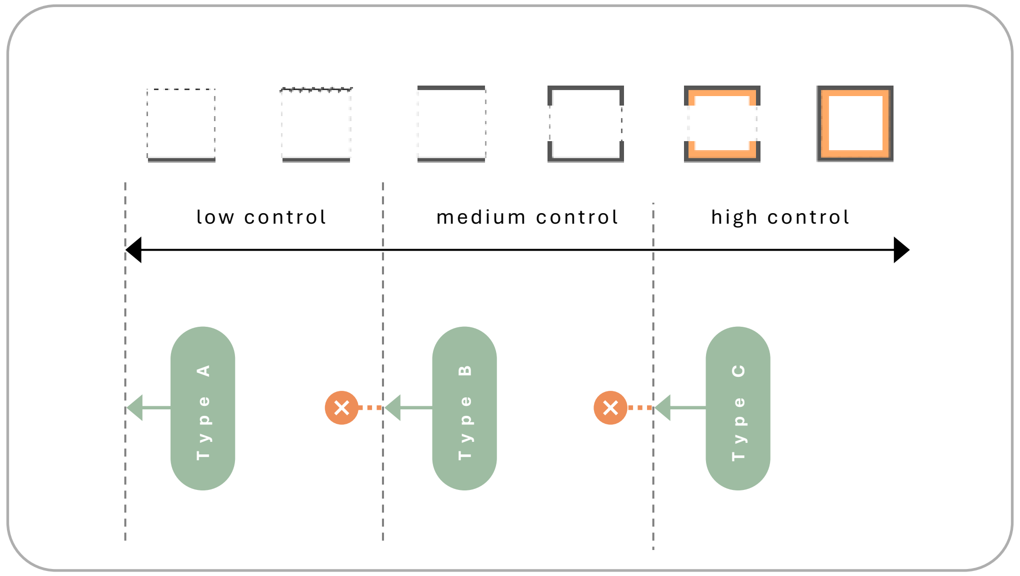
7 Spatial typologies

Spaces can be grouped into **3 types** based on their **tolerance for the outdoor environment**. This considers the minimum level of environmental control a space requires to remain functional. The categorisation applies to both temperate and tropical climates.

Type A – High outdoor tolerance

Type B – Medium outdoor tolerance

Type C – Low outdoor tolerance



Argument / supporting data:

Type A - High outdoor tolerance

Within this category, spaces possess the **capacity** to function with low environmental control, either for parts of the year or year-round (Fig. 7a). During this low-control period, spaces require little to no active control over temperature, sun, light, wind or rain* (*often strategically avoided). On a practical level, they have low demands for sensitive equipment, furnishings or spatial setups.

- **Typical spatial functions**: living, gathering or relaxing. Spaces like living rooms, kitchens, terrace seating or circulation have a high tolerance for parts of the year. Other spaces, typically those with a permanent outdoor function like gardens, parks or playgrounds, have a year-round high tolerance.

Type B - Medium outdoor tolerance

Spaces in this category are unable to adopt low-control measures, but can function effectively with medium control, either for parts of the year or year-round (Fig. 7a). During this period, spaces require reliable protection from the rain and, occasionally, increased control over solar gain and light, to protect users, furnishings, or equipment. The need for a more predictable environment is due to prolonged occupation, tasks requiring concentration, or the use of sensitive equipment, furnishings or setups.

- **Typical spatial functions**: work, study, sleep, hygiene and services. This includes spaces like offices, study spaces, classrooms, toilets, bedrooms, etc.

Type C - Low outdoor tolerance

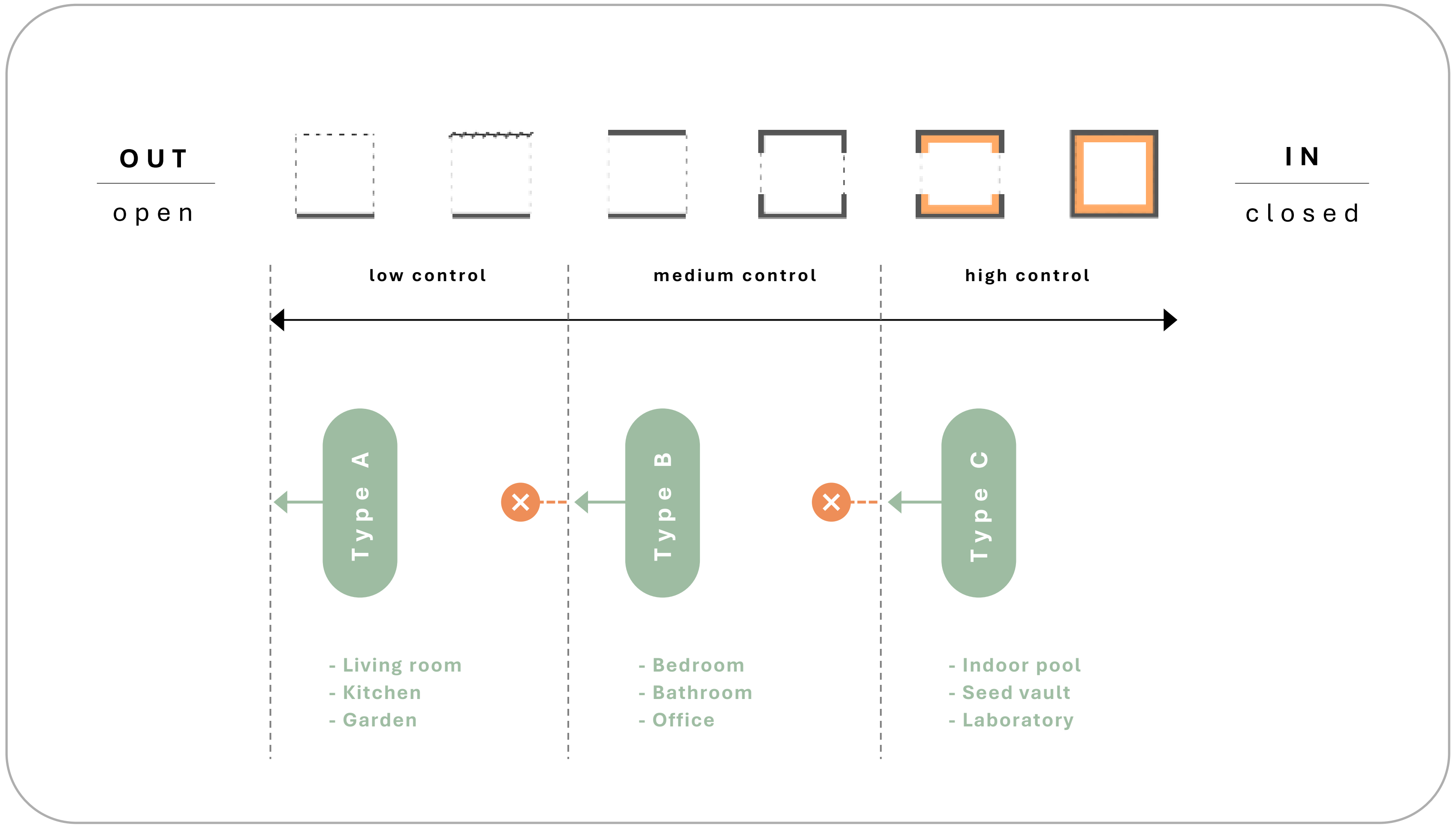
These spaces demand a highly stable and controlled environment year-round, irrespective of external conditions. They lack the flexibility to adopt lower control measures, often with precise requirements for temperature, humidity, air purity, or lighting, due to the sensitivity of the contents or processes they house (Fig. 7a).

- **Typical spaces**: Laboratories, archives, seed vaults, data centres, clean rooms, indoor pools...

What does this mean for design?

The proposed classification helps assess the suitability of a given space for Baubotanik design and facilitates a more strategic application of Baubotanik in a given programme:

- **Suitability assessment**: Type A spaces are the most compatible with Baubotanik, allowing for a full integration of living structures. Type B spaces are also viable, typically through hybrid designs that combine living and technical elements. Type C spaces are fundamentally incompatible with the Baubotanik approach and should be designed using conventional construction.
- **Programmatic strategy:** For a defined brief, this classification helps identify which programmatic elements to target with Baubotanik. For a project with an undefined brief, finding functions that fall within Type A and B will result in a project more naturally aligned with the principles and potentials of Baubotanik.



7a Spatial typologies classification. Type A spaces have the capacity to remain functional in the low-control zone. They may also revert to higher control zones at certain times of the year. Type B spaces have the capacity to remain functional in the medium-control zone, but not in the low-control zone. Type C spaces can only function with high-control measures.

04

CONCLUSION & DISCUSSION

Conclusion and discussion

Conclusion

This research set out to investigate the architectural potentials and limitations of Baubotanik design through the following questions: ***What can Baubotanik do?*** and ***What do spaces need?*** By analysing both precedents and spatial requirements across temperate and tropical climates, the study identifies **seven key design considerations** for the strategic application of Baubotanik in spatial design.

Overall, we have found **climate**, **seasons,** and **tree species** together with **spatial typologies, building approach**, and **environmental control** to play an important role in the viability and success of a project.

The findings demonstrate that Baubotanik's architectural potential is **strongest** where structural development can evolve over time and where growth patterns and form flexibility are maximised through species selection. Both from a construction and environmental control point of view, it is most suited to low-control spaces, with hybrid construction extending its usability well into the medium-control zone. However, its use for high-control spaces is currently limited, highlighting the need for conventional construction in such spaces. This holds especially true in temperate climates requiring fully sealed environments for significant parts of the year.

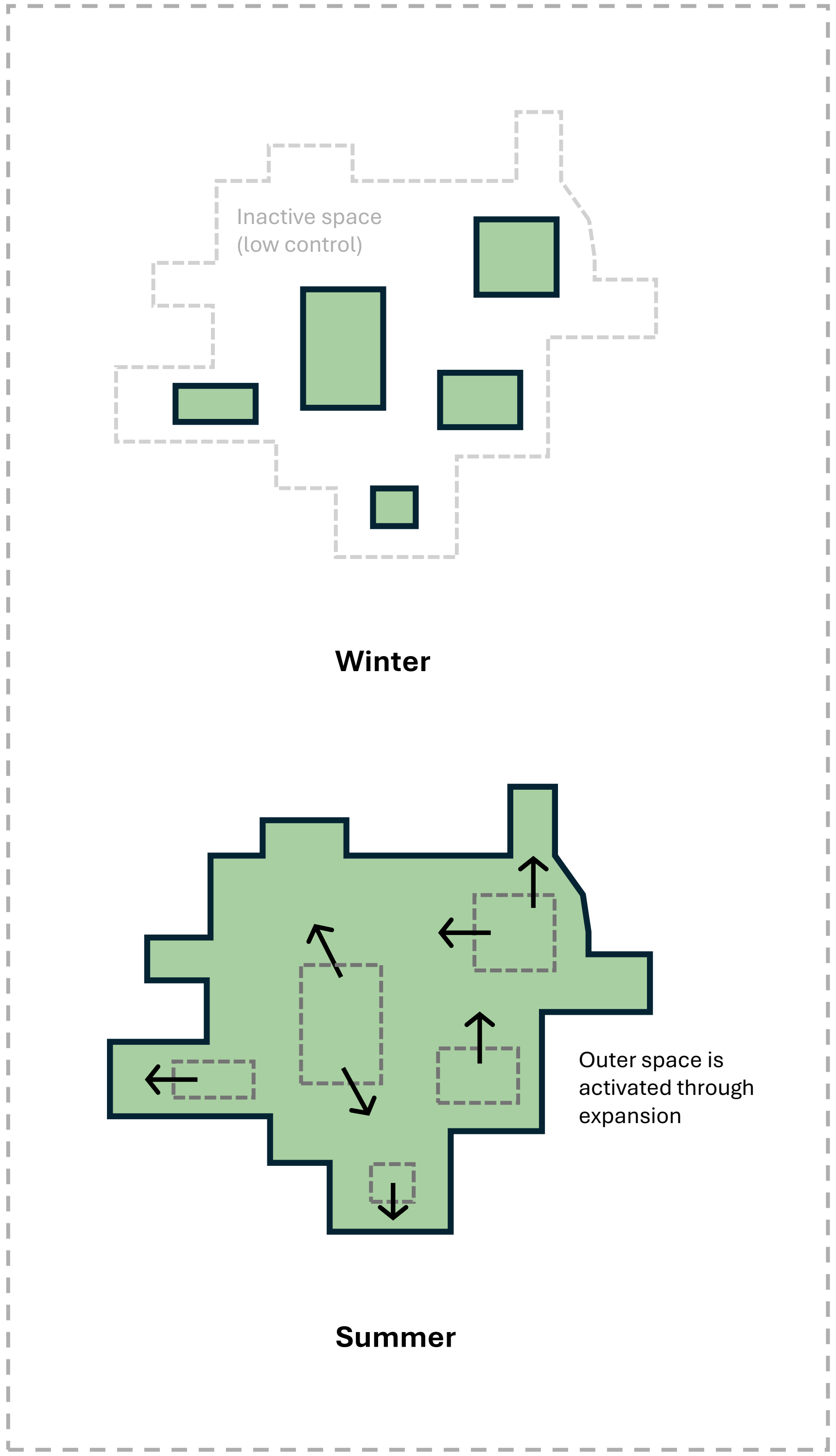
Throughout most of the analysis, tropical environments have demonstrated a higher compatibility with Baubotanik design year-round, due to the outward-oriented nature shared by the two. Meanwhile, temperate climates are most suited in the summer, with colder periods presenting a significant design challenge for Baubotanik, due to the need for fully sealed enclosures.

Discussion (future directions, ideas)

Despite some clear shortcomings, Baubotanik has significant potential in architectural practice. By placing living structures at the foreground of design, it promotes a dynamic design approach; one that embraces growth, change, adaptability and a closer connection with its surroundings. This highlights some important design strategies:

1 **Seasonal changes and adaptability.** Baubotanik is not a static system; it grows, it breathes, and it changes with the seasons. As a designer, **how can you build with the seasons? What does it mean to live with the seasons?**
In practice, this could mean a **fluid footprint** that expands or contracts across seasons, in response to the weather and the level of control required. In such a scenario, there could be small, compact cores (controlled spaces) and wider (semi-)outdoor spaces (lower control). In winter, the usable footprint would be small, but as soon as the weather allows, the footprint can expand outwards, activating the lower control areas (Fig. 1). By placing adaptability at the core of the design, we allow the design this to adopt the dynamic nature of Baubotanik.

2 **Hybridisation.** Combining **living** and **technical** systems considerably extends the scope of Baubotanik design, both in terms of climate control and architectural expression. The interplay between these two systems is an exciting prospect from a designer's perspective. Whether as temporary supports or as a permanent part of the project, suitable technical elements could include steel, timber, bamboo or masonry as structural components, but also fabric, membranes, lightweight claddings, as non-structural additions. Although currently understudied, material compatibility has plenty of research potential for future investigations.



1 Adaptability and shifting boundaries. Seasonal changes enable room for play in the design. The usable footprint expands and contracts across seasons.

3 One project, multiple construction techniques. Given the difficulty in building high-control spaces with current baubotanical techniques, a project with a complex programme could benefit from multiple construction techniques. For example, Baubotanik construction for low- and medium-control spaces, complemented by conventional construction for high-control spaces. Here, **programmatic targeting** could be an effective design tool. In the long term, investigating the viability of high-control spaces with Baubotanik will be a key research topic: Is it possible to create high-control spaces with Baubotanik? What techniques and materials are necessary?

These complementary strategies constitute an important **starting-point** in Baubotanik design. It allows informed, contextual design on the one hand and technical advancements on the other, to push its boundaries.

Validity, limitations and additional research directions

Climate zones: The analysis was limited to two major climate zones - tropical and temperate - with a more focused investigation of the tropical monsoon and temperate oceanic subcategories. This leaves other climatic contexts unexplored and open to future research.

Tree species: The study considered only a narrow selection of tree species within the two chosen climate zones, owing to the limited number of existing Baubotanik projects. This raises questions about the architectural potential, growth behaviours, and spatial possibilities of untested species. Further botanical and structural research is needed to assess whether other candidates could be compatible for spatial design.

Project selection: Projects with structural potential were favoured during the selection - those where the trees play a load-bearing or semi-structural role. This emphasis favours a particular reading of Baubotanik as a structurally expressive or performative design method. Future research could benefit from a broader inclusion of non-structural or more ephemeral uses to explore alternative potentials, such as shading, enclosure or spatial experience.

Empirical validation: While climate and spatial analyses in this study offer a strong theoretical basis for compatibility, empirical validation remains limited. There is a need for long-term studies across climate zones and seasonal cycles to evaluate the performance, maintenance, and user experience of Baubotanik structures in real-world conditions.

Cultural limitations: This paper has mainly considered potentials and limitations on a technical level. However, also noteworthy are design limitations of a non-technical nature. In Southeast Asia, for example, religious and cultural constraints around tree manipulation could influence not only the design possibilities of a project, but also the feasibility of future practical research experiments. Other possible limitations should also be investigated and presented as valid design limitations.

05

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