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Trees in Planters—A Case Study of Time-Related Aspects

Christoph Fleckenstein [1], Vjosa Dervishi [2], Mohammad A. Rahman [2,*], Thomas Rötzer [2], Stephan Pauleit [2] and Ferdinand Ludwig [1]

[1] Department of Architecture, School of Engineering and Design, Technical University of Munich, 80333 München, Germany
[2] Department of Life Science Systems, School of Life Sciences, Technical University of Munich, 80333 München, Germany
* Correspondence: ma.rahman@tum.de

Abstract: Urban spaces are often dominated by paved surfaces and ongoing processes of densification; consequently, intensifying the urban heat island effect. In order to strengthen the liveability of urban spaces, an adequate amount of green spaces is needed. Trees in planters are an alternative greening solution; however, the lack of root space due to underground infrastructure poses a challenge. Furthermore, temporal aspects such as tree growth, tree death, and growth responses to environmental factors are frequently overlooked in projects that use trees in planters. In multiple case studies that employ the method "Research through Drawing" we analyse five selected projects, which deal in sharply contrasting ways with the temporal aspects of trees in planters. Our results show that promising approaches exist, albeit they are not described explicitly in either written or graphical form. Consequently, temporal aspects are only vaguely considered in the projects' design concept. This results in the neglect of the further use of trees in planters in temporary projects, or in the disregard for tree death in the design and responses to it in permanent projects. Therefore, the potential of trees in planters as an alternative and complementary greening solution remain unexploited. To overcome this, a coherent temporal approach that considers growth, death of plant parts or whole plants, and that is developed as an integral part of the design concept and communicated graphically, would ensure that the involved actors and their respective tasks are well coordinated throughout the lifetime of a project.

Keywords: building greening; concept; design; growth; landscape architecture; open space; planter; root space; time; tree

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1. Introduction

Continued urban densification amplifies the urban heat island effect (UHI) [1] and can create monotonous open spaces dominated by hard surfaces such as concrete, asphalt, paving or steel [2]. The resulting decline of environmental quality in inner urban areas has severe negative effects on human health and well-being, notably due to heat stress and a lack of contact with nature [3–5]. Climate change is predicted to exacerbate these risks [5]. An increase of vegetated surfaces as green infrastructure is growing in recognition as an effective strategy to adapt cities to climate change and improve urban quality of life [5–7]. The important basis of a liveable city is good urban planning, in which there is as much green infrastructure with trees planted in the ground as possible [7]. While preserving existing trees and planting new ones is an effective way to reduce thermal stress in urban areas, via shading and evapotranspirational cooling [8–13], the aesthetic and recreational values of trees [14] contribute equally to human well-being [15]. Furthermore, an adequate amount of green surfaces can reduce noise pollution [8,16], break the monotony [2], and change the perception [6] of urban open spaces in densely built inner cities. However, urban planning is subject to constraints whereby planting new trees conflicts with a lack of rooting space caused by continued densification and underground infrastructures such as parking garages or sewer systems [17,18]. Therefore, trees in planters may serve as an alternative greening solution in highly densified urban open spaces, as well as an option for the greening of buildings to complement trees in the ground. Using trees in planters, nevertheless, comes with several difficulties; due to the confined root space, environmental factors such as heat, drought, nutrient availability, air pollutants or vandalism may have a stronger impact on the growth and vitality of a tree [1,18–20]. This calls for a high level of maintenance, including continuous and reliable irrigation and regular inspections at short intervals. Even if these conditions are met, the life expectancy of a tree in a planter is likely lower than that of a comparable tree growing in the ground [21,22].

Temporal aspects, such as growth, death of plant parts or whole plants, growth responses to environmental factors—such as wind, competition for light and resources—, mechanical injuries and their interplay with facets namely, planter type, mechanical wear, maintenance, or growing site, are highly relevant in the conception and design of projects that employ trees in planters.

This study is part of the research project "Trees in planters as an urban climate effective measure to adapt to climate change" at the Technical University of Munich. It aims to contribute to the scientific base to fully utilise the potential of trees in planters as an alternative greening solution. The objective of this paper is to improve the knowledge on time-based design concepts for the use of trees in planters in the advanced stage of the research project. It aims to answer the following three main questions.

1. Which approaches dealing with the temporal aspects of trees in planters can be identified in realised landscape design and architecture projects and what are the project's most important temporal processes?
2. How are the different life spans of the trees in planters, the planters themselves and the built structures considered in the project and how do they influence each other?
3. Are temporal aspects represented in the project and which documents exist that address temporal aspects?

2. Materials and Methods

To answer the before mentioned research questions, our research investigated multiple case studies in which five realised landscape design and architecture projects displaying different approaches were analysed to understand how temporal aspects of trees in planters are dealt with and how these aspects are integrated into the overall design.

2.1. Systematic Identification and Selection of Landscape Design and Architecture Projects

In order to identify relevant landscape design and architecture projects that could serve as case studies, the initial criterion was that the projects must use trees in planters for greening, either in public open spaces or on buildings. The use of keywords in Internet search engines such as Google and relevant journals were combined with the snowballing research method [23]. The employed keywords were: tree, planting pot, planter, container, open space, building, house, greenery, greening. The keywords planter, planting pot and container are often and synonymously used in the research and practice field of horticulture, tree nurseries and planter manufacturing. The keywords open space, building and house specified the spatial situation in which trees in planters are used. Lastly, tree, greenery and greening put the search focus on projects that use vegetation in alternative greening solutions. This systematic search was based on an already existing list of eight landscape design and architecture projects that fulfilled most of the criteria explored in the paper, which had been collected in recent years. It was applied to find more projects and to ensure that no relevant project, that developed an approach to deal with temporal aspects of trees in planters, was overlooked.

The number of case studies analysed in more detail was set as five. On the one hand, this number allowed for a sufficiently deep qualitative examination of the projects and, at the same time, provided a satisfactory overview of different approaches. To select the five representative projects that use trees in planters, we defined the following criteria as the most crucial:

- Climate zone: The focus of this study is on the temperate Central European climate, thus we decided to target projects in a comparable climate zone, facing similar climatic conditions.
- Spatial context: The projects should be located in a dense urban setting, such as a city centre, either in (public) open spaces or on buildings.
- Temporal aspects: Sufficient information should be available to assess the project's dynamics and its development over time.
- Most of the identified projects aim for crown diameters of no more than three meters. To ensure that the growth conditions typical of trees in planters actually occur, a value of no more than four cubic meters was set for the volume of the planters [11,24,25].
- To allow for an overview, two to three of the five projects should be located in (public) open spaces, while the others should use trees in planters on buildings.
- The selected projects should include recently realised projects to reflect current design trends (between 2000 and 2020), and also older projects to consider the planning, as well as the actual implementation of maintenance measures over time.

2.2. Methods for Analysis of the Case Studies

In order to develop a sound project description as a basis for further analysis, a literature review was combined with interviews (see Appendix A) and personal communication (see Appendix B). Keywords related to the projects were used in the literature review to search for scientific publications, book chapters, plans and drawings and grey literature (Internet articles and brochures). The literature list comprised about 42 publications. The documents found were analysed in terms of the context of the projects, their design and aim, their temporal aspects and the architect's expectation on its future development as well as the current stage of development of the project. The further analysis included tree species, tree size at planting, design and size of planters and maintenance measures.

The interviews were semi-structured and conducted either by video conference or face-to-face on site. The average interview duration was about 45 min. A total of six interviews were conducted with eight interview partners. All interviews were transcribed for the evaluation. The focus of the evaluation was on the possible lifespan of trees in planters, necessary maintenance measures to preserve the tree, planter design and possibilities for the use of trees in planters as well as insights on the projects. The personal communication was conducted via e-mail with one person and specific questions to one project (Courtyard City Hall).

To understand the temporal character and interaction of processes in the case studies, the method of "research through drawing" was chosen [26,27]. This method is well established in architectural research. "Research through drawing" as an analysis method enables the acquisition of knowledge and understanding of architecture projects, through the iterative process for generating analytic drawings based on plans, drawings, photographs, articles, literature and interviews with the planners of the projects [27,28]. "When drawing is re-examined in the research context, where it is now being performed as a definitive activity within art and design research, it can be understood in its functionality as a driving force that moves the research inquiry forward" [27]. The graphical analysis illustrates the complexity of interactions and patterns found in the analysed projects and is based on the collected information during the drawing process [29]. The method of the "inventive analysis" enables to close information gaps revealed in the graphical analysis in a logical way by following the found interactions and patterns [30]. Through closing the revealed gaps and following the project's patterns and interactions, a possible future development of the project displaying the unmentioned aspects can be illustrated in the graphical analysis.

The combination of the applied methods allowed for the development of time diagrams as a method for analysing and visualising the temporal aspects, along with processes and interactions of the past, present and future of the selected projects, and the involvement of the different actors (landscape architect, architect, developer, nursery, gardener, planter manufacturer).

The time diagram is an assumption based on the available information about the project and the authors' knowledge about trees in planters and represents one possible future development of the project. This approach aims to reveal important interactions and identify critical temporal aspects of the project. Figure 1 presents the graphical elements of the time diagrams. The green frame in the time diagram marks the lead time for the project, which includes cultivating the tree in the nursery, planning and building the project. The blue frame covers the projected lifetime of the project and is referred to as the "Project time frame" and includes the growth development of the trees in the planters, the planter life span and the life span of the open space or building with all processes related to the different life spans. "Project start" marks the beginning and "Project end" the closure of the "Project time frame".

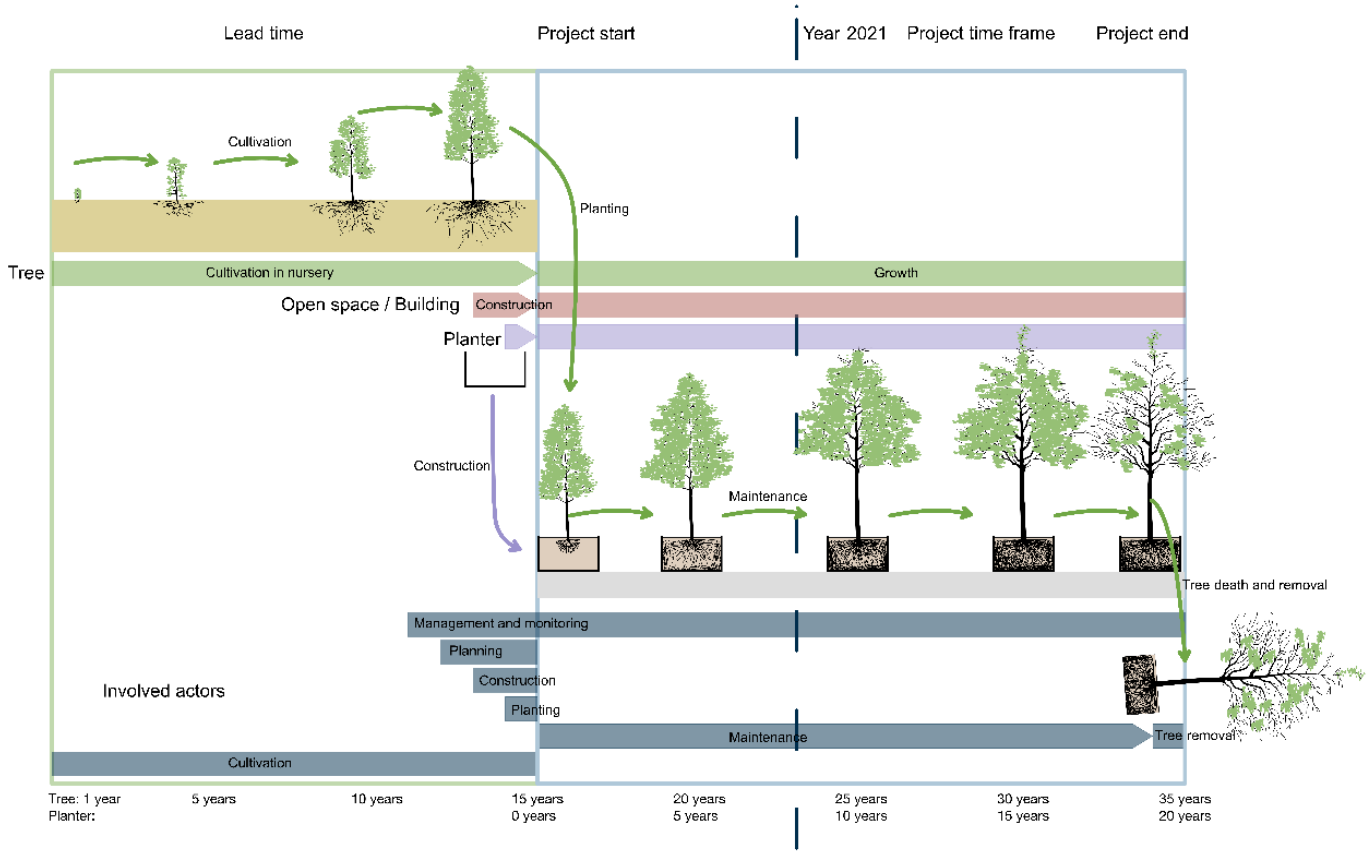

Figure 1. Exemplary representation of the graphical elements of the time diagrams.

The temporal aspects are presented in the form of bars. The pointed end of a bar indicates the transition from one process section to the next. The blunt end of a bar indicates the end of the process in the project for the element shown. The temporal aspects of the tree(s) are represented by green bars and include the growing in the nursery, the growth in the planter and the transplantation of the tree or, if applicable, the death of the tree. In case of tree replacement, the temporal aspects of the next tree generation is represented by a separate bar. The growing period in the nursery is shown in detail graphically above the temporal aspects of the tree and, for better readability of the diagram, only for the first tree generation. The temporal aspects of the open space or building are represented with red bars and include the information if the built structure already existed in the pre-project phase and if re-design, construction, renovation or deconstruction have taken place. The temporal aspects of the planter are shown in purple and include construction and subsequent use as well as repair and final removal, if applicable. When and how the actors are involved in the project is shown by blue bars for the individual actors. The tasks of the actors are described in the corresponding bars and process stages.

The arrows mark actions that affect the tree and the planter and are labelled accordingly. The names of the actions and the tasks of the actors are identical, so that interactions can be identified. Below the frames are the ages for the tree and the planter; year dates mark the age of the tree and the planter at a certain point in the project. The time information also serves to mark how much time individual processes in the project take. The dashed line marks the year 2021 and serves as the pointer on the age of the project at the time of the analysis and in which project stage it is situated now.

3. Results

In this section, we present the results of our systematic search of projects and selection of five projects for the case studies based on the criteria mentioned above. Each of the case studies is then briefly described and their temporal aspects are graphically analysed and represented in a time diagram.

3.1. Identification of Landscape Design and Architecture Projects

Through the systematic search of projects, a total of 32 potentially suitable projects for the analysis were identified (Appendix C). The selection was informed by the criteria mentioned above, but was made on a subjective level in several discussions of the authors. The intersubjective comprehensibility of the project selection is therefore important [31].

The following five projects were selected as case studies:

A. Tour de la biodiversité, Paris, France
B. Bosco Verticale, Milan, Italy
C. Brown Hart Gardens, London, England
D. Courtyard City Hall, Poznan, Poland
E. Orangery Castle Freyr, Hastière, Belgium

Project A was selected based on the idea of working with chasmophytes (plants growing in rock crevices), the comprehensive data provided by Maison Edouard Francois (MEF) and the possibility of an interview with Mathieu Chatenet, the project leader. Project B was selected because of its prominence in landscape architecture and architecture and the very data base. The contrasting approaches of project A and B also influenced the selection. Project C was considered because of its long history and the clear lack of an approach to deal with the temporal aspects. The comprehensive database made it possible to derive the temporal aspects of the project, which were crucial for its selection. Project D was selected because of its approach to planned tree transplantation, which, however, was only mentioned in the personal correspondence with the project's architect Jola Starzak. This approach is a unique feature among the long-term projects found. Project E was chosen because of the paradigm shift of replacing the planter rather than the tree, which has been successfully practiced for over 300 years. The information for this project is exclusively based on the experience report from the owner of the castle, Axel Bonaert.

The selected projects are located in Europe (Figure 2) and include two buildings (projects A and B), two public open spaces (projects C and D) and a historic example (project E).

Figure 2. Location of the five selected projects in Europe. (Own graphic based on https://www.openstreetmap.de/karte/ (accessed on 15 July 2022)).

3.2. Analysis of the Case Studies

3.2.1. Tour de la Biodiversité, Paris, France

Project Description

The "Tour de la biodiversité" was designed by "Maison Edouard Francois" (MEF) and the winning entry of a competition in 2010, completed in 2016 (Chatenet, Mathieu, personal communication, 23 June 2020). The competition aimed to overcome the negatively connoted image of residential towers in Paris by showing their potential for liveability and to dispel the image of grey concrete blocks (Chatenet, Mathieu, pers. comm., 23 June 2020). To reach that goal, the design uses 400 trees, shrubs and climbing plants in planting pots, including four tree species and a total of 22 different species to grow a biodiverse façade, intended to act as a nature hub to spread seeds in the surrounding green spaces, and as a habitat and food supply for animals [32]. The design idea of a long-lasting green façade is put into practice by using small and slow growing plants at the start of planting process.

To find the appropriate tree species, testing pertaining to growth rate and vitality behaviour of different tree species began in 2012 at the nursery "Ecole du Breuil", where it concluded in 2015 [32]. Following the design idea, the seeds for the trees were collected in the surrounding forest of Paris and cultivated in the nursery for four years [32]. The tree species (*Pinus nigra* ARNOLD ssp. *Corsicana*, *Pinus nigra* ARNOLD ssp. *Salzmannii*, *Quercus pubescens* WILLD., *Quercus robur* L.) were chosen based on their ability to live as chasmophytes on a minimal water and nutrient supply, resulting in minimal growth (Chatenet, Mathieu, pers. comm., 23 June 2020). The expected growth of the plants is represented in two graphics that show the state of the plants on the façade at the start of planting and the expected state after 10–15 years after planting (Figure 3) [33].

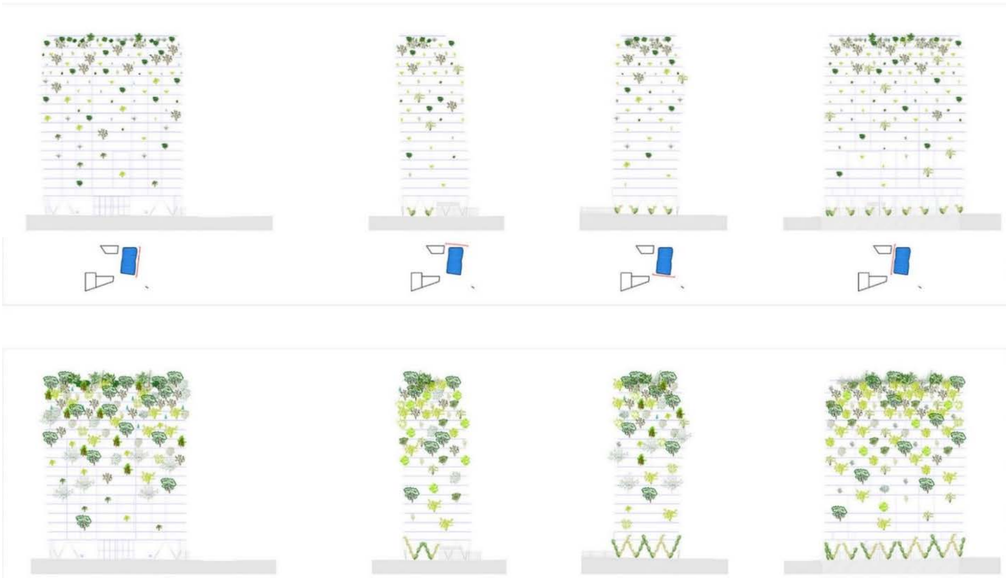

Figure 3. Expected plant growth and facade cover by the architects in the first year (**top**) and 10–15 years after completion (**bottom**) and each façade orientation; east, north, south and west (from left to right). The façade orientation is also marked with a red line in the plan in the middle of the figure according to each façade face. The tour de la biodiversité is the blue marked building in the plan. (Maison Edouard Francois 2016).

The specially designed planters are installed as single planters on the façade several meters apart from each other (Figure 4). They are made of stainless steel and have a narrow tube shape with a diameter of 25 cm and a height of 350 cm (volume of ca. 0.17 m^3) [34] to imitate a crevice for growing chasmophytes (Chatenet, Mathieu, pers. comm., 23 June 2020). The planters are expected to have the same lifespan as the building itself (Chatenet, Mathieu, pers. comm., 23 June 2020). Further stimulating the tree's chasmophytic characteristics, the automated irrigation system regularly supplies the trees with just enough water to survive and thus keeping the growth rate low and steady. It is expected that tree death will occur and is solved with the technical solution of tree removal with a special vacuum pump and tree replacement (Chatenet, Mathieu, pers. comm., 23 June 2020). A team of specially trained gardeners carries out the maintenance, along with routine checks on the irrigation system and planters, and will be involved in case of tree death and replacement (Chatenet, Mathieu, pers. comm., 23 June 2020).

Figure 4. Tube-like planters with small trees on the Tour de la biodiversité after completion (Pierre L'Excellent 2016).

Graphical Analysis

The lead time of the "Tour de la biodiversité" (Figure 5) consists of the planning process, starting in 2010, testing and cultivation of the trees in the nursery, starting in 2012, start of the construction phase in 2014 and the completion of the building in 2016. The project ends with the deconstruction of the building after a likely lifetime of about 90 years. Based on five expert interviews (Belz, Martin, pers. comm., 21 January 2021; Dierksen, Christoph and Wolber, Peter, pers. comm., 22 September 2020; Kluska, Christoph and Hartwich, Jens, pers. comm., 23 January 2020; Wiesendanger Urs, pers. comm., 10 December 2020; Böse, Oliver, pers. comm., 11 January 2021), we assume that the life span of the trees in this project is around 30 years. In case of tree death, the trees will be removed and replaced with a new one by the gardener. Four years prior to tree replacement the seeds must be collected, to ensure that the next tree generation cultivated will be available for that event. This indicates that the nursery must collect seeds and cultivate trees in an ongoing passive process to have suitable trees available for the project at any given point in time, in the event of unexpected cases of tree death. The renovation of the building can happen in sync with tree replacement every 30 years. The owner is responsible for managing and monitoring all processes. This task could extend beyond the project end, if a new project will follow the current in the same location.

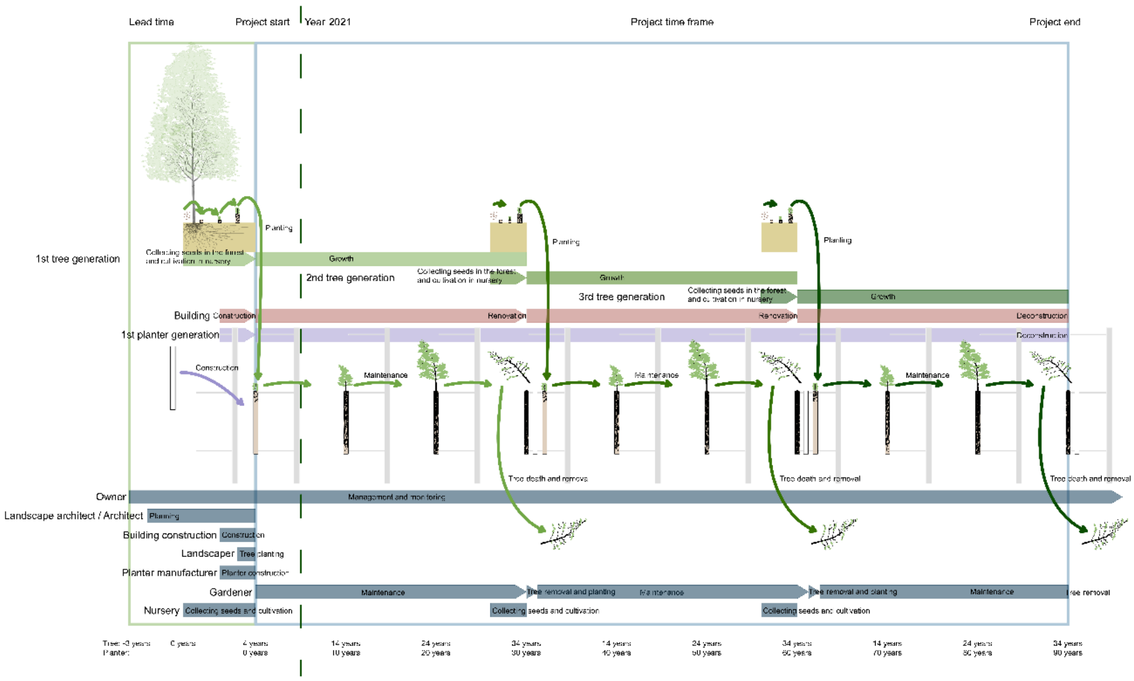

Figure 5. Time diagram of "Tour de la biodiversité".

3.2.2. Bosco Verticale, Milan, Italy

Project Description

The Bosco Verticale, designed by Stefano Boeri Archetetti, consists of two residential towers [35]. Out of the 20,000 plants, 700 trees are used to green the balconies of the two residential towers in Milan, Italy [2]. In 2015 the Bosco Verticale was completed. The project aims to cover the facades with plants to reduce the thermal load and improve the microclimate of the residential towers, as well as increase the biodiversity in urban areas [2]. Not only does the sheer mass of 20,000 plants ensure the goal of the project but so, too, does the variety of 148 plant species. The design idea is to perceive the Bosco Verticale as a set of processes and not as an architectural object (Figure 6) [35].

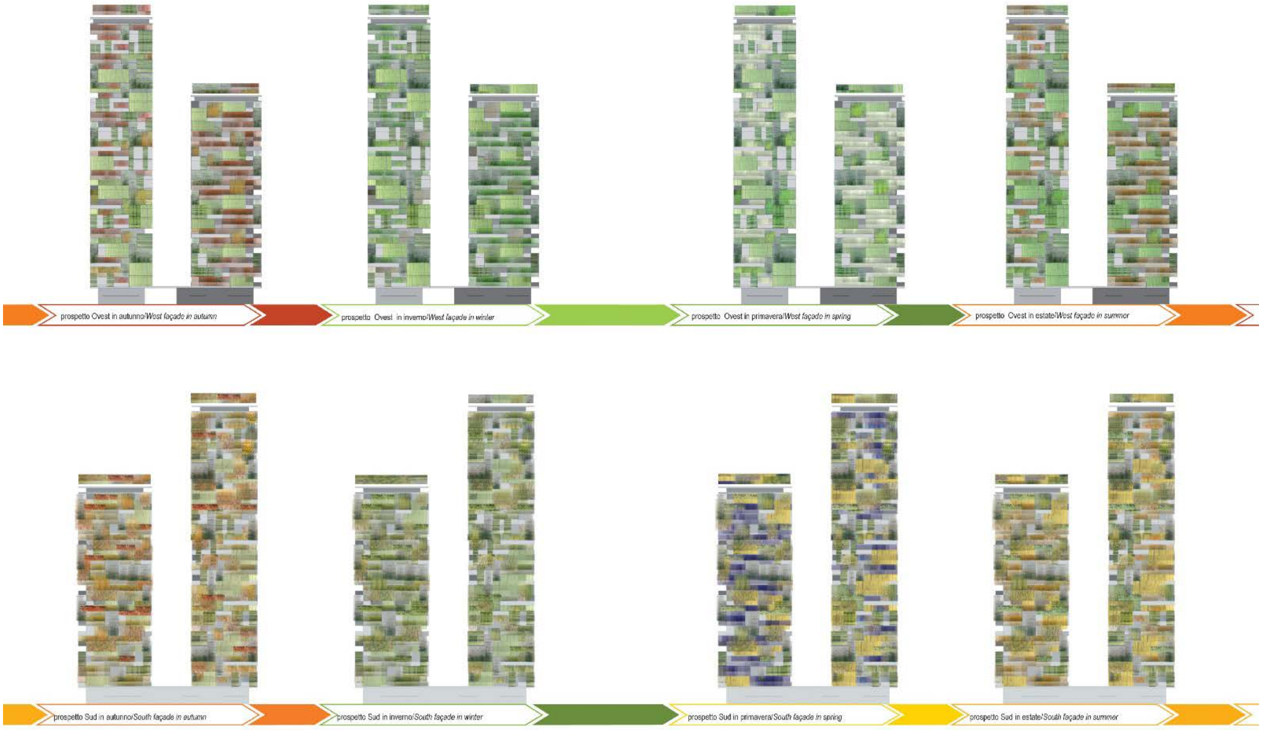

Figure 6. Seasonal change (autumn, winter, spring, summer (left to right)) of the facades of Bosco Verticale, represented by the west façade (**top**) and the south façade (**bottom**) (Stefano Boeri Architetti 2009).

Twenty-three tree species (i.e.,: Corylus colurna, Fagus sylvatica, Gleditsia triacanthos 'Sunburst', Quercus ilex, Acer campestre, Fraxinus ornus, Parrotia persica, Prunus subhirtella) were selected according to the following requirements: resistant to wind, tolerant of pruning, resistant to parasites, cause no allergies, tolerant of the urban climate and pollution, produce no fruits, deciduous, tolerant to excessive sunshine and shade and simple to maintain [2]. The location of the trees on the building was based on these requirements. Wind tunnel testing was conducted to measure the resistance to wind and to decide where the different tree species can be planted on the façade. Therefore, tall trees were only planted up to half of the height of the towers [2]. The plants are planted in concrete planters which form the balcony balustrades (Figure 7). The planters possess rectangular shapes which follow the outline of the balconies and are 1.1 m high and 1.1 m deep for trees and 0.5 m high and 0.5 m deep for herbs and shrubs [2]. The volume of the planter is defined by the size of the balcony and ranges from ca. 1.5 to 10.5 cubic meters in volume. The concrete planters are fitted with a waterproofing membrane and a protective sheeting against root damage inside the planter walls, as per international standards of green roofs [2]. The trees were at least 15 years old and up to six meters tall at the time of planting. They were pre-cultivated in aerated planters to reduce the growth of circular roots. Big trees had a root ball diameter of 90 cm and medium trees of 70–75 cm [2]. Maintenance consists of regular watering, fertilising and pruning [2]. Monitoring and general maintenance are carried out 3–6 times a year; pruning is carried out 1–2 times a year [2].

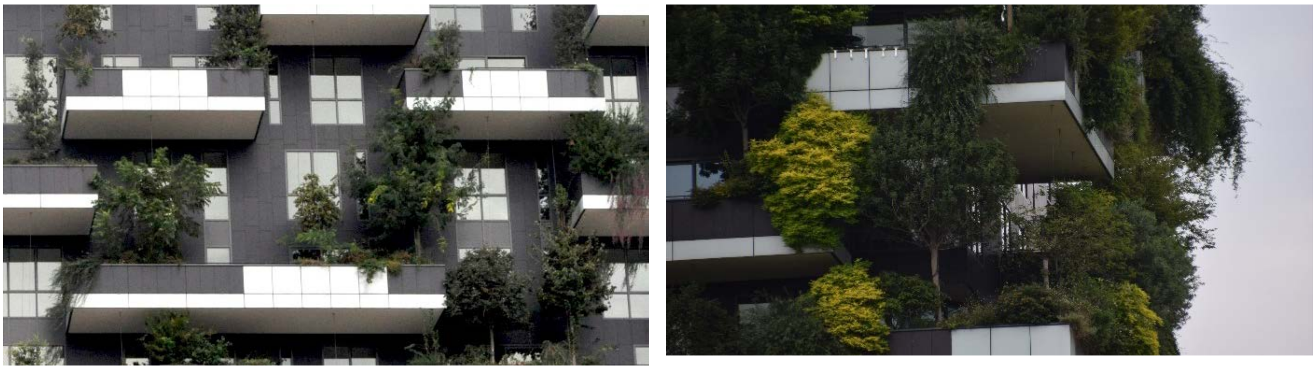

Figure 7. Vegetation on the Bosco Verticale; (**left**): in 2014 (Phil Beard 2014); (**right**): in 2019 (George Groutas 2019).

Graphical Analysis

The time diagram "Bosco Verticale" (Figure 8) shows that the cultivation of the trees started before the planning process of the project began. The owner Fondo Porta Nuova Isola started with the development of the area of the Bosco Verticale in 2005 [36] and contracted Studio Boeri in 2008 with the planning [37]. Construction started in 2009 [37]. The project ends with the deconstruction of the building after a likely lifetime of about 100 years. Based on five expert interviews (Belz, Martin, pers. comm., 21 January 2021; Dierksen, Christoph and Wolber, Peter, pers. comm., 22 September 2020; Kluska, Christoph and Hartwich, Jens, pers. comm., 23 January 2020; Wiesendanger Urs, pers. comm., 10 December 2020; Böse, Oliver, pers. comm., 11 January 2021), we assume that the big trees are likely to die earlier than the small trees and shrubs. Because of a bigger root ball, the big trees will reach the limits of the planter sooner and will be strongly restricted in their growth because of that. A likely point of tree death for the big trees is assumed to be around 30 years after planting. When the tree dies, it will be cut down and removed, leaving the root stock in the planter. Following natural succession, the other plants will grow into the gap and compensate for the plant loss to some extent. The planters waterproofing membrane and protective sheeting against root penetration will last for around 50 years [38]. Consequently, planter repair will be required including the removal of plants and substrate and the introduction of new substrate and plants. Building renovations are assumed to be every 25 years, in sync with the planter repair after 50 years. The owner is responsible for managing and monitoring of all processes. This task can extend beyond the point of the project end, if a new project will follow the current one in the same location.

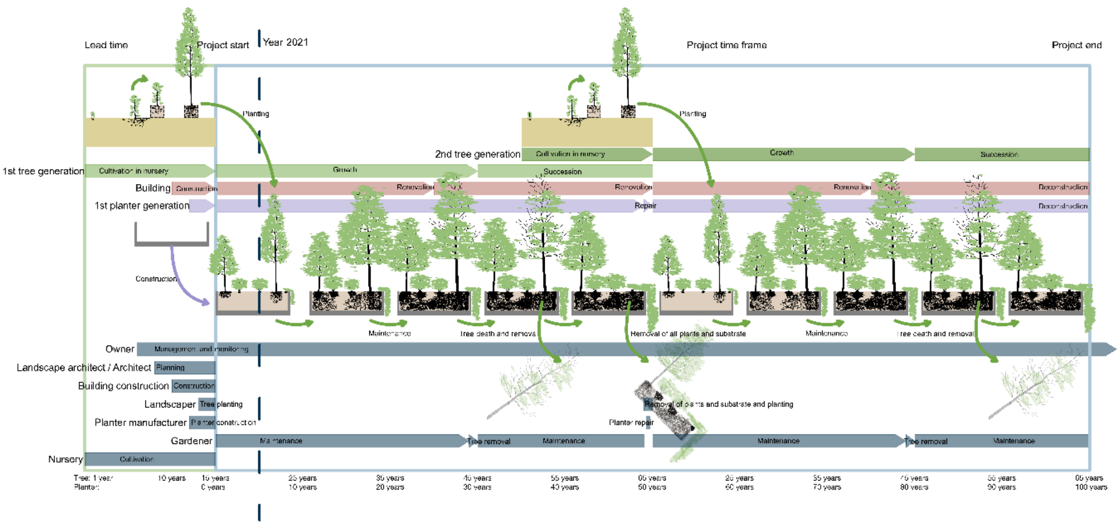

Figure 8. Time diagram of "Bosco Verticale".

3.2.3. Brown Hart Gardens, London, Great Britain

Project Description

Brown Hart Gardens, in London, were developed out of "Brown Street" and "Hart Street" as a central community garden for a residential project in 1888 [39]. The garden was covered by a substation following the electrification of London between 1903 and 1905 [39,40]. As compensation for the lost garden, the substation's roof was designed as a garden with trees in planters, elevated 3 m above street level and was opened in 1905 [39,41]. The trees in planters were still vital in a photograph in 1930 [39], which indicates regular crown pruning when compared to the photograph of 1905. However, the exact time of tree removal is unclear. When the garden was closed in the 1980s [42], there were no longer trees in planters in the garden. After being a deserted space for over 20 years, trees in planters were again planted and the garden was re-opened on a limited basis in 2007 [39]. The Westminster city council announced in 2007 to improve the public realm across Westminster, including Brown Hart Gardens [43]. This led to a redesign of Brown Hart Gardens as a public space by the Building Design Partnership (BDP) architecture office. It was completed in 2013 [44]. The redesign aims to create a flexible public space with "a range of appropriate activities for residents, visitors and workers within the area" [39]. To cover the high maintenance costs, the Gardens are supposed to generate their own income with staging events and a new café on site [45].

To realise the aim of a multifunctional public space, specially designed movable, as well as stationary planters were used [45]. Semi-mature trees were planted in stationary planters and perennials, herbs and evergreens were in the movable planters (Figure 9) [45]. Golden Rain trees (*Koelreuteria paniculata*) were planted with an estimated size of 18–20 cm stem circumference, to achieve an immediate aesthetic effect. The stationary planters are rectangular and are equipped with integrated tree anchors, along with lights and power sockets [46] following the multifunctional design idea. Based on BDP's plans, the planters are 1.80 × 1.2 m and 1 m high. The cladding of the planter and the integrated lights and power sockets reduce the substrate volume to ca. 1.25 m^3. Grosvenor, the owner of Brown Hart Garden, manages the maintenance of the garden [47], but no further information on maintenance measures is available.

Figure 9. Brown Hart Gardens in 2014 (Andy Thornley 2014).

Graphical Analysis

The time diagram “Brown Hart Gardens” (Figure 10) focuses on the current redesign of the open space implemented in 2013. It shows that the gardens existed before the currently implemented design was planned and that it was already owned by Grosvenor. The lead time consists of the planning process, started in 2010 [39], the (re)construction of the open space, completed in 2013 and the tree cultivation in the nursery. Following van Dooren’s [48] time frame for open spaces and based on the rich history of “Brown Hart Gardens”, a redesign will probably take place 30 to 40 years after the completion of the project. Thus, we assume that a redesign after 30 to 40 years will mark the end of the current project. In recently published photographs on Foursquare, the trees show the first signs of partial branch dieback eight years after planting [49]. Based on five expert interviews (Belz, Martin, pers. comm., 21 January 2021; Dierksen, Christoph and Wolber, Peter, pers. comm., 22. September 2020; Kluska, Christoph and Hartwich, Jens, pers. comm., 23 January 2020; Wiesendanger Urs, pers. comm., 10 December 2020; Böse, Oliver, pers. comm., 11 January 2021), a likely lifespan is estimated to be 15 to 20 years. We assume that tree replacement will be carried out when a stage of an unattractive tree appearance is reached. The owner is responsible for managing and monitoring all processes. This task can extend beyond the point of the project end, if a new project will follow the current one in the same location.

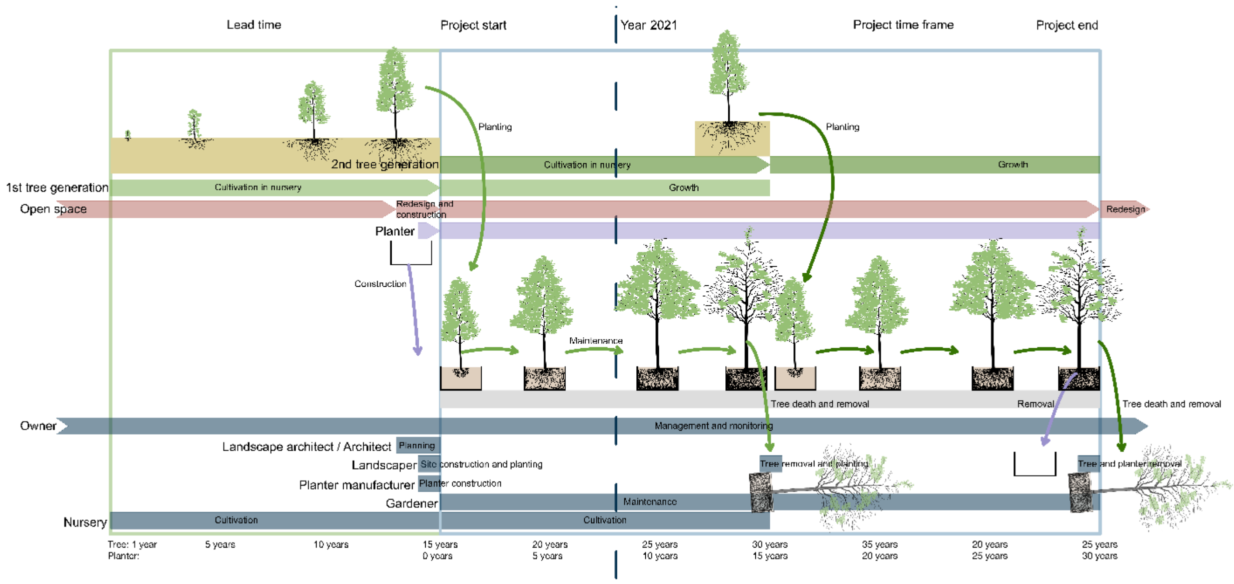

Figure 10. Time diagram of “Brown Hart Gardens”.

3.2.4. Courtyard City Hall, Poznan, Poland

Project Description

The courtyard of the City Hall in Poznan was transformed from a parking lot into a public open space according to the design by Atelier Starzak Strebicki in 2015. The completion of the project was achieved in 2019 [50]. The design uses movable planters and benches to allow a flexible organisation of the space for events and to meet the needs of different social groups in the courtyard [51]. The benches are parked with their backside against triangular planters in their daily set-up. This allows people to find a quiet and relaxing spot in the courtyard to spend time [52]. The new design of the courtyard was carried out in three phases (Figure 11). Phase 0 involved the removal of the parking lot. Phase 1 opened the courtyard to public access and was furnished with benches and planters during the period of 2015 to 2016. An exhibition system and complementary street furniture were added in Phase 2, which concluded the design of the courtyard in 2019 [50,52].

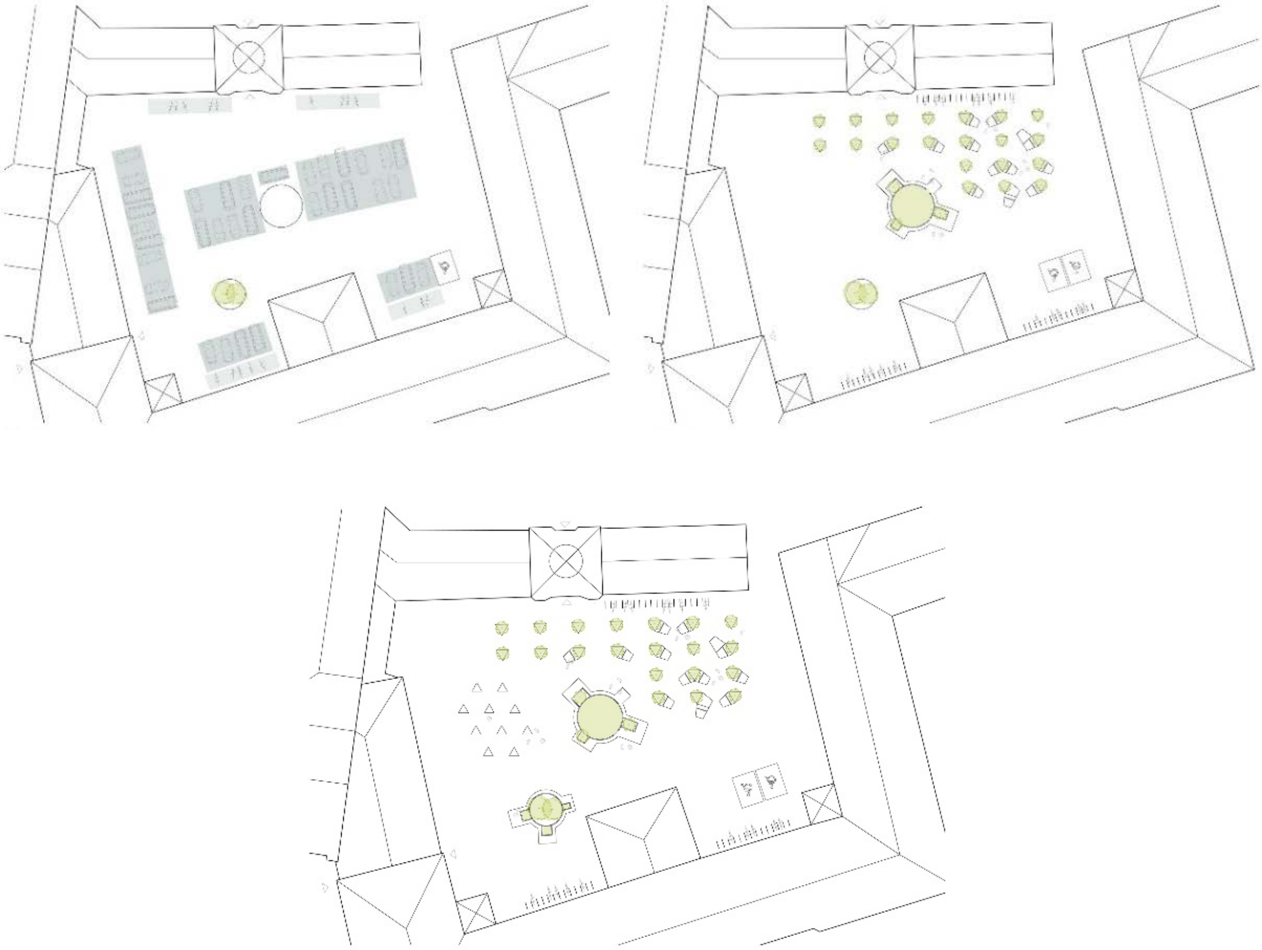

Figure 11. Transformation process of the Courtyard City Hall by Atelier Starzak Strebicki in 2015. Top left: Phase 0: 2014—existing situation—parking in the courtyard; top right: Phase 1: 2015–2016—public accessible courtyard with street furniture; bottom left: Phase 2: 2016–2019—publicly accessible courtyard with street furniture and new round bench and exhibition system.

Six different tree species (*Platanus x hispanica, Tilia cordata, Betula utilis, Acer rubrum, Acer campestre, Cerasus serrulate*) are used across the 20 planters, with a total of 20 trees (one tree per planter) (Figure 12). Flowers and grasses are added to the planters to complement the trees (Starzak, Jola, pers. comm., 11 May 2021). The trees were selected out of a nursery's stock and were planted with an approximate size of 20–25 cm stem circumference. The planters are triangular with two-meter-long sides and a height of 0.74 m, allowing for a volume of ca. 0.95 m^3. The walls and floors are made out of sheet metal. Squared timber cladding covers the outside of the planters [53]. A team of gardeners of the city council Poznan carries out the maintenance (Starzak, Jola, pers. comm., 11 May 2021). The planned transplantation of the trees into green spaces of Poznan, once they are too large for the planters and their replacement with small trees, is an important aspect of the project to reach its aims (Starzak, Jola, pers. comm., 11 May 2021). The design was intended to be kept for five years, but the furniture and planters are still in good condition. The new plan is to keep them as long as they last (Starzak, Jola, pers. comm., 11 May 2021).

Figure 12. Courtyard City Hall, Poznan after completion in 2019 (Atelier Starzak Strebicki 2019).

Graphical Analysis

The time diagram (Figure 13) shows that the courtyard existed and was owned by the City of Poznan before the lead time of the project started. Planning process started in 2014, followed by the construction in 2015 and was completed in 2019 [50]. The project's time frame corresponds to van Dooren's [48] time frames for open spaces of 15–30 years and the average durability of wooden benches and planters of 15 years [54]. The project will end when the furniture and planters are no longer in good order, which will conclude with a redesign of the courtyard. According to Starzak (pers. comm., 11 May 2021), the cultivation of the first tree generation started approximately 15 years before planting. Considering the planned tree transplantation, tree and planter size and based on five expert interviews, the trees will stay on average a maximum of five years in the planters. The City of Poznan is responsible for managing and monitoring of the project. This task will extend beyond the project's end and into the following project.

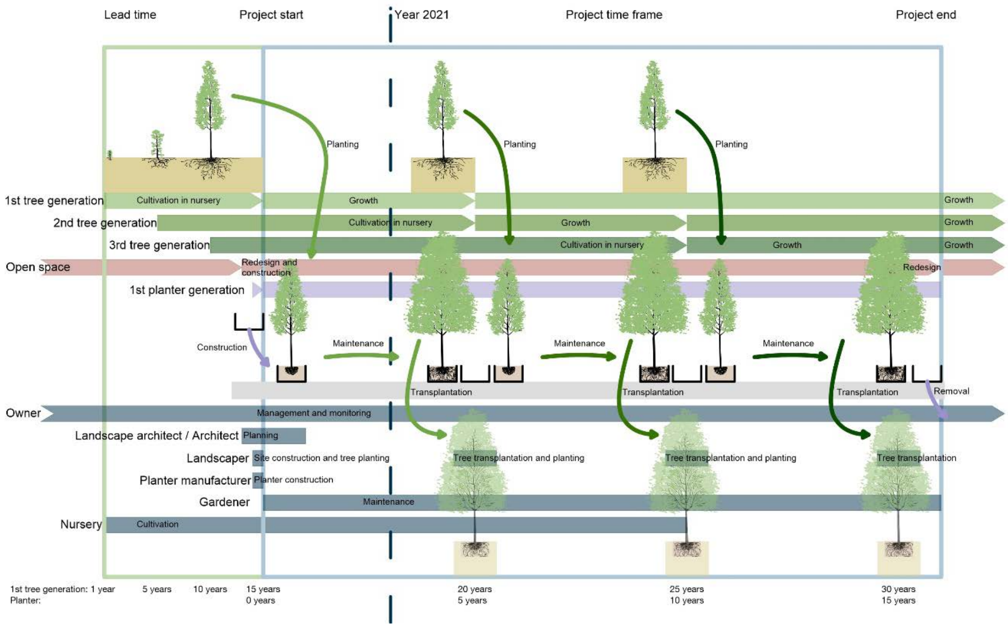

Figure 13. Time diagram of "Courtyard City Hall".

3.2.5. Orangery Castle Freyr, Hastière, Belgium

Project Description

The orange trees in the Orangery of the Castle Freyr are claimed to be the oldest trees in planters of Europe [55]. The trees arrived between 1711 and 1737 at Castle Freyr. The estimated age of the trees ranges between 300 and 350 years, and have been kept in planters ever since [55]. The goal of this project is to keep the orange trees healthy.

There are 23 orange trees of that age in total. The trees survived several wars, storms, floods, and periods of negligence [55]. The great-grandmother of the castle's current owner, Axel Bonaert, advised in a diary on how to maintain the orange trees with a precise scheme [55]. After the last gardener left in 1975 [55], the owners of the castle took over the maintenance of the orange trees. Following this change, the owners had to go through a learning process on how to carry out the maintenance advice [55]. Wrong execution of the diary's watering advice led to over-irrigation and waterlogging in the substrate which caused stress in the form of leaf colouring and leaf loss [55]. Therefore, today's watering practice is rather to react to dry stress symptoms, than to risk waterlogging by over-irrigation [55]. The trees are pruned twice a year. Overshoots are pruned in September and in May: only branches that need pruning, will be pruned. This pruning strategy leads to a healthy crown with vigorous leaf growth [55]. Fertilizer is applied regularly after a period of using no fertilizer. This increases leaf growth without increasing the root density too much between potting [55]. An important part of the maintenance scheme is root pruning. The trees are moved inside around the 15th of October and moved outside on the 1st of May [55].

Based on photographs, the trees are estimated to be two meters high and with a crown diameter of two meters. The planters are 0.78 $\times$ 0.78 m and 0.7 high with a volume of ca. 0.4 m^3 and are made from oak wood [55]. The planters consist of four poles which are connected by boards and iron bars. The iron bars are movable, which allows the removal of the boards to have access to the roots [55]. In recent years a new type of planter with stronger iron reinforcement but with the same principles as the old one was developed and implemented. It is assumed that the new planters will last longer than 15 years, which could influence the maintenance cycle concerning root pruning [55].

Graphical Analysis

The time diagram (Figure 14) focuses on the current state and recent history of the project due to its over 300 years of history. The event of repotting and root pruning marks the beginning and end of a 15-year-long maintenance cycle in the time diagram. The planters are manufactured and replaced in sync with repotting and root pruning. The task of management was passed from one owner generation to the next one. Based on the project's history, the project time frame has no definitive end. It will end when the orange trees die but it could also be extended if a new generation of orange trees replaces the current one. Another possible project end would be if the next generation of owners will give the orange trees away.

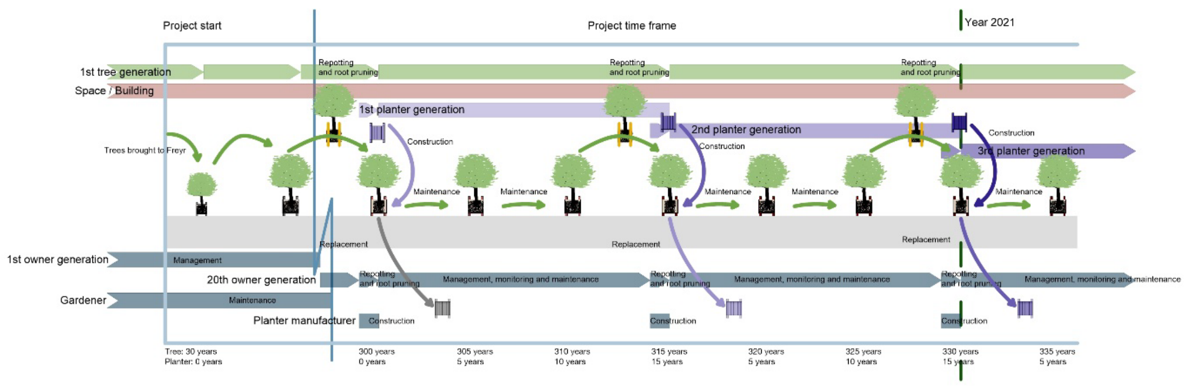

Figure 14. Time diagram of "Orangery Castle Freyr".

4. Discussion

In this section we discuss our research design (Section 4.1) and answer the research questions (Sections 4.2–4.4).

4.1. Method and Project Selection

This case study shows that the selected projects have developed approaches to deal with temporal aspects for trees in planters. The methods used to analyse the projects and their temporal aspects were successful in finding the existing temporal aspects and showing how they are linked to each other. Yet, temporal aspects were sometimes not represented or mentioned or fully comprehensible by the information found. Hence, the drawing process revealed that concrete plans and unmentioned aspects must be represented as equal information in the graphical analysis to be able to understand patterns and correlations between the temporal processes. Therefore, the method of "inventive analysis" was used to show these non-described necessities and interactions [30]. We found out that the aim of the project and its approach need to fit in a coherent way to be successful. The graphical analysis shows the process between the approach and the aim of the project and enables for a logical comprehensibility of whether the project's approach and aim are coherent. In addition, the chosen methods made it possible to make assumptions about the future development of the project and to check their plausibility based on the time diagrams.

The informative value of the time diagrams is limited to a plausible estimate of the future development of the projects. The predictions made in the time diagrams are based on an extensive literature research on growth factors of trees in planters and our own field experiments in our research project (Rahman et al., forthcoming paper). Therefore, the "project time frames" were closely linked to plausible lifetimes of open spaces (15–30 years [48]), buildings (80–100 years [54]) and renovation cycles (20–40 years [54]). However, the authors are aware that the development of the projects can run contrary to the assumptions made.

The analysis is of a qualitative nature and the statements made cannot be derived from an arbitrary selection of other projects [56]. However, this approach makes it possible to gain insights from the analysis that will contribute to the development of new concepts [56].

The chosen methods do not enable to make statements about appropriate trees species and planter types to be used for trees in planters or give guidelines for planning projects with trees in planters. Empiric studies on these topics are needed to make such statements [57,58]. Therefore, the paper focused on the temporal aspects of trees in planters in realised projects and how they are addressed in the design approach.

4.2. Identified Approaches

With regard to our first research questions, namely "Which approaches to dealing with the temporal aspects of trees in planters can be identified in realised landscape design and architecture projects and what are the project's most important temporal processes?", the analysis of the selected case studies identified different approaches to deal with the temporal aspects of trees in planters (Table 1).

Table 1. Identified design approaches of the five analysed projects.

Project A	Slow tree growth by using the chasmophytic principle, combined with tree replacement in case of tree death
Project B	Succession and robustness through great plant variety in large shared planters
Project C	Tree replacement in case of tree death as a rescue measure to restore the aesthetic value of the space
Project D	Planned tree transplantation and replacement when the tree grows to large for the planter
Project E	Regular root pruning to adapt the tree to the restricted root space combined with repotting and planter replacement

The five projects cover to varying degrees the temporal aspects in their design approach. None of them considers the entire life cycle from design to renewal but project D (Poznan) stands out with a detailed design that covers every phase of the project up to its completion and its planned tree transplantation. This measure explicitly addresses the temporal aspects of tree growth and limited root space. The further use of trees by transplanting them into various green spaces in Poznan displays that the possibilities, which trees in planters enable, are utilised. With its very detailed maintenance measures and precise time schedule, Project E has proven for centuries that its approach works. However, the displayed high demand in maintenance limits its successful transfer into a design for a public open space [20]. Moreover, projects A and B do consider temporal aspects in their different design approach, but both fail to answer how tree death will impact the overall design. Based on the graphical analysis, we can only assume that the use of a big variety of plant species in shared planters in project B provides enough resilience for the design [7,18], that a loss of single plants will not result in a failure of the design. Project C, on the other hand, does not consider dynamic aspects of plant growth in its design, thus only providing a static representation of vegetation reduced to its aesthetics. Problems with this approach became evident as no provisions were made in the plan to cope with observed partial dieback of plants. Instead, this approach entirely relies on the capability of the tree species to provide enough resilience for the design.

4.3. Consideration of Different Life Spans

The second research question regards the analysed projects' life spans, namely "How are the different life spans of the trees in planters, the planters themselves and the built structures considered in the project and how do they influence each other?". (Table 2)

Table 2. Life spans considered in the five analysed projects.

Project A	Trees are expected to reach a life span of at least 15 years and tree death is considered to happen. The life span of the planters is not considered. The architects expect that the planters will last as long as the building (Chatenet, Mathieu, pers. comm., 23 June 2020). The building's life span is not considered.
Project B	Tree life span is not explicitly considered. The architects present the project as a set of processes [35] this implicates that tree removal in case of tree death is considered. The planter's life span is not considered, but strongly connected to the endurance of the waterproofing membrane and protective sheeting against root damage, which will last 30–50 years based on experiences with green roofs [38]. Life span of the building is not considered in the project's approach.
Project C	The life span of trees in planters is not considered in the approach of project C. Also, the life spans of the planters and the open space are not considered in the project's approach.
Project D	The life span of the trees in planters is connected to a size-relation of tree and planter. The tree will be transplanted when it grows too large for the planter. The planters were expected to last five years, but according to the architect Jola Starzak (pers. comm., 11 May 2021) the planters are still in good condition and will last longer than expected. The life span of the open space is not considered as it is expected to outlast the project's time frame.
Project E	Tree life span is connected to root growth. The trees outlast the planter life spans. The planters last between 15–30 years [55]. The life span of the castle is not considered

Project D considers the different life spans. The planned tree transplantation extents the life span of the trees beyond their time in the planters. The planter-tree-size-relation suits the short duration of about 5 years, in which the trees will stay in the planters [24,59,60]. The triangular planter shape and the thermally insulated planter walls [53] can reduce circular root growth [61] and thermal stress in the root zone [62–65] and therefore be beneficial for a vital root structure that is suitable for transplanting [57,66–68]. However, the planter design includes no obvious features that would suit an easy tree replacement. Such a feature could extent the lifespan of the planters. The life span of the courtyard will outlast the project time frame. We found out in the graphical analysis that the durability of the planters and root growth are the defining life spans in project E. They are addressed by regular planter replacement, root pruning and repotting of the trees. The life spans of the trees and the castle shift into the background.

The life span of the trees in planters in project A is only considered in the first 15 years after completion and that tree death is expected to happen at some point. The chasmophytic growth strategy of the trees is used to reach a long tree life span. The planter design of project A serves the purpose of imitating a crevice: the habitat of chasmophytes and using very small trees at the point of planting strengthens this strategy. The narrow tube shape of the planter increases the risk of strangulation by girdling roots [69]. Based on the shape of the planter, it can be assumed that tree removal might not be possible if the planter is fully rooted [70]. The architect's expectation that the planter will last as long as the building is not feasible according to the expertise of planter manufacturers (Böse, Oliver, pers. comm., 11 January 2021; Wiesendanger, Urs, pers. comm., 10 December 2020). Project B only partially considers the different life spans by expecting tree death to happen at some point. Especially the planter life span is not considered. Even though, the graphical analysis shows that it is the defining life span in this project. Despite offering an adequate rooting volume [24,59,60] and using shared planters to add to the resilience of the design approach by increasing the available root volume, as well as the available water and nutrient storage [22], the graphical analysis shows that the removal of all plants and substrate is necessary to repair or replace damaged waterproofing membranes and root protective sheeting after 30–50 years [38].

Despite its rich history with trees in planters, the different life spans are not considered in project C which became apparent in the graphical analysis. Thus, tree death is not considered, and tree replacement may only be used as a rescue measure to restore the aesthetics of the place. Further, the inadequately chosen tree-planter-size-relation, if the goal is to keep the trees longer than for 15 to 20 years in the planter, indicated by partial branch dieback of trees eight years after completion [49], emphasises the lack of life span considerations.

None of the analysed projects provide information about the expected life span of the building or open space and what will happen after deconstruction, re-design or re-purpose. In the graphical analysis it became apparent that the consideration of the different life spans of the tree, the planter, and open space or building in the approach also needs a close communication between the involved actors to ensure a good coordination of the different temporal processes.

4.4. Representation of Temporal Aspects

With regard to our third research question, namely "Are temporal aspects represented in the project and which documents exist that address temporal aspects?", we can give the following answers (Table 3):

Table 3. Found representations of temporal aspects in the five analysed projects.

Project A	Two graphics showing the growth expectations according to the architect [33] at the point completion and 15 years later.
Project B	Graphical representation of seasonal changes of the facades.
Project C	No representation of temporal aspects in graphics or texts.
Project D	Represents the construction process in three graphics.
Project E	Detailed written representation of temporal aspects, but no graphical representation.

In project D, time is explicitly represented in graphics that show every phase that the project went through up to its completion (Figure 11). Tree replacement and transplantation are central elements of the project, but they are not represented as part of the design concept. However, it is communicated clearly who is involved in the process of tree transplantation (Poznan city council, landscaper, nursery) and what the actors will do (site selection for transplantation, tree transplantation, providing new trees) (Starzak, Jola, pers. comm., 11 May 2021). Project E has a detailed written project description that mentions all important temporal aspects and their consideration. The temporal aspects are communicated in detail and a close cooperation between the involved actors is clearly stated. Therefore, the approaches and the aims of projects D and E are linked coherently.

Considerations of temporal aspects in project A and their effect on the design are represented in two graphics (Figure 3) showing the growth expectations according to the architect [33]. However, time is not addressed further than 15 years after planting. Even so, tree death is expected to occur, there is no indication on how tree death will affect the design. Gaps in the green facade due to plant loss could therefore have a significant impact on the perception of the building. Further, the communication on how to address the temporal aspects seems to be not well transferred from the design approach to the maintenance of the project regarding the fact that fertilizer was used at the request of the city council of Paris to promote faster growth and to reach the goal of a green façade sooner [32]. This measure is contrary to the characteristics of chasmophytes and stands against the aim of a long-lasting green façade [32]. The limited representation of temporal aspects in project B shows an inadequate communication of temporal aspects on the one hand and detailed descriptions of maintenance measures [2] indicate a good communication of temporal aspects between the involved actors on the other hand. The linkage between approaches and aims of the projects A and B is there but limited representation of temporal aspects, information gaps on planter maintenance and contrary maintenance measures show logic gaps in the coherent linkage between project approaches and aims.

No representation of temporal aspects in graphics or text exist in project C. The stressed trees, due to reaching the limits of the root space, lack of maintenance or disease [71], indicate an inadequate communication and failure of reaching the project's aim of aesthetical appearance of the trees and the open space. Therefore, the approach and the aim of project C have no coherent connection.

All cases have in common that no detailed graphical representation of temporal aspects exists that show the expected project development until a possible end of the project.

5. Conclusions

The aim of the present study was to better understand the temporal aspects of trees in planters. The analyses carried out were not intended to lead to a final evaluation or ranking of the projects, but to illustrate the multi-layered aspects. As a result, it becomes clear that aspects such as the choice of suitable plant species or the construction of the planters are indeed relevant, but what is ultimately decisive is that the objective, the technical implementation and the handling of temporal aspects must build on each other coherently. The present study shows, especially with the help of the graphic analyses, that the many different, interlinked temporal processes are highly complex. However, this complexity is often not adequately reflected in the conception and communication of the projects. This can be illustrated, for example, by the Brown Hard Gardens project (C), whose primary goal is to present the largest possible, healthy, visually attractive trees. The temporal approach, however, is limited to replacing specimens that appear obviously diseased. This means that the goal cannot actually be achieved in the long run; the project is always deficient due to the discrepancy between the aim and the handling of temporality. The Orangery (Project D), in contrast, shows that this point is technically solvable over extremely long periods of time. Here, though, it is questionable whether the associated maintenance effort is sustainable. Project A illustrates that showing different vitality and development states can also be part of a concept. However, the communication of the concept is deficient here, as it partly did not reach the user (keyword: fertilisation). This shows how important the communication of the concept is for the success of the project. For this purpose, graphical representations of the concepts are important, which show the interplay of temporal aspects of trees in planters, such as growth, death of plant parts or whole plants, growth responses to environmental factors—such as wind, competition for light, resources and mechanical injuries—and with facets such as planter type, mechanical wear, maintenance, or growing. This complex interplay is often neglected. If conceptual considerations in this regard exist at all, hardly any of them are explicitly elaborated by drawings or other forms of graphical representation. This can be considered a major shortcoming since the graphic representation of the temporal aspects of a design concept is important when they are at the front of the design reasoning [48]. According to van Dooren [48] conceptual design drawings refer to a landscape that does not yet exist, and therefore, these drawings are crucial in the debate about a new landscape. Time-based representations in drawings that consider the temporal aspects of a project, are well-known in today's landscape architecture practice but far from being used in in a widespread manner [48].

From this case study, the following can be concluded: Projects with trees in planters can be implemented in different ways and with a variety of different plant species, but they can only fulfil the expectations placed on them if temporal aspects are fully understood and made an essential element of the overall concept, and they are clearly and comprehensibly described and (graphically) communicated to ensure that the actors involved (landscape architect, architect, developer, nursery, gardener, planter manufacturer) and their respective tasks (planning, construction, pre-cultivation, production, planting, maintenance) are well coordinated.

In the further progress of the research project "Trees in planters as an urban climate effective measure to adapt to climate change", empiric research on the growth development of trees in planters will be conducted and a systematic of time-based design concepts for the use of trees in planters will be developed to act as planning guidelines for planners, designer and city councils.

Author Contributions: Conceptualisation, C.F. and F.L.; methodology, C.F.; validation, C.F., V.D., M.A.R., T.R., S.P. and F.L.; formal analysis, C.F.; investigation, C.F.; writing—original draft, C.F.; writing—review and editing, C.F., V.D., M.A.R., T.R., S.P. and F.L.; visualisation, C.F.; supervision, F.L.; project administration, F.L.; funding acquisition, T.R., S.P. and F.L. All authors have read and agreed to the published version of the manuscript.

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Appendix A

List of interview partners:

Mathieu Chatenet
Architect at Maison Eduard Francois
Project supervisor "Tour de la biodeiversité"
7. Passage Thiéré. 75011 Paris, France
23 June 2020
Oliver Böse
Engineering Department at Optigrün International AG
Am Birkenstock 15–19, 72505 Krauchenwies-Göggingen, Germany
11 January 2021
Urs Wiesendanger
Specialist consultant for planters and vegetation systems at duroplant
Allmendweg 1, 3662 Seftigen, Switzerland
10 December 2020
Christoph Kluska and Jens Hartwich
Sales management and tree management at Bruns-Pflanzen-Export GmbH & Co. KG
Johann-Bruns-Allee 1, 26160 Bad Zwischenahn, Germany
23 January 2020
Christoph Dierksen and Peter Wolber
Managing director and sales consultation at Wilhelm Ley GmbH
Baumschulenweg 20, 53340 Meckenheim, Germany
22 September 2020
Martin Belz
Project supervisor at Jakob Leonhards Söhne GmbH & Co. KG
Düsseldorfer Straße 255, 42327 Wuppertal, Germany
21 January 2021
Questionnaire:
Part 1: Personal background
How long are you working in the company/office?
How long are working in the field of trees in planting pots?
What are your interests in working with trees in planting pots?

Part 2: Topics
Planting pots
What criteria must a planter be designed to in order to ensure optimal care of the tree?
To what extent do different planter systems influence the growth and vitality of the tree?

Site
Which site conditions influence the tree in the planter and how does the tree influence in return its site?
Are there site conditions that make the use of planting pots difficult or impossible?
To what extent does the site affect the maintenance effort?

Life cycle
What does an optimal maintenance of trees in planting pots include?
What are the life cycles and durations of up to date systems and what are the criteria behind it?
What failure rates have been observed and what are the reasons?
What influence has an optimal maintenance to the life duration of the system (tree and planting pot) and the vitality of the tree?
Potentials/Limits
What are the biggest problems, what are the biggest potentials?
Within which temperature limits (heat, freezing cold) do trees in planting pots function/survive?

Part 3: Outlook
How do you assess the future development and use of trees in planting pots as a measure for greening urban spaces?
In your opinion, what are the biggest obstacles/hurdles to overcome during the planning and realisation process of trees in planting pots?

Appendix B

Personal communication

Jola Starzak
Founder of Atelier Starzak Strebicki
Botaniczna 14, 60-586 Poznan, Poland
11 May 2021

Appendix C

Table A1. Thirty-two found projects, fulfilled criteria highlighted in green, missed criteria highlighted in red.

Project	Location	Year	Climate	Tree Size (Stem Circum-Ference in cm)	Planter Size (Volume in Litres)	Spatial Situation	Representation of Time
HotSpotPots	Freising	2012	Humid temperate	25–30	1000–1500	Public open space	No
Wanderbaum-allee Stuttgart	Stuttgart	2019	Humid temperate	10–12	100	Public open space	Yes
Wanderbaum-allee München	Munich	1994	Humid temperate	20–25	100	Public open space	No
Brown Hart Gardens	London	2013	Humid temperate	12–14	1000	Public open space	No
Landhausplatz	Innsbruck	2010	Cold temperate	No data	8000–12,000	Public open space	No
Race Street Peer	Philadelphia	2011	Warm temperate	No data	7300	Public open space	No
Courtyard City Hall	Poznan	2019	Warm temperate	20–25	950	Public open space	Yes
Rathbone Square	London	2017	Humid temperate	25–30	No data	Public open space	No

Table A1. *Cont.*

Project	Location	Year	Climate	Tree Size (Stem Circum-Ference in cm)	Planter Size (Volume in Litres)	Spatial Situation	Representation of Time
The Tide	London	2019	Humid temperate	25–30	No data	Public open space	No
Seoullo 7017 Skygarden	Seoul	2017	Cold temperate	No data	No data	Public open space	No
Roemer Plaza	Boston	2016	Cold temperate	No data	No data	Public open space	No
BIAG Schwanthaler-straße	Munich	No data	Humid temperate	No data	No data	Public open space	No
Orangery Castle Freyr	Hastière	1718	Warm temperate	40–60	450	Private open space	Yes
Wanderbäume Würzburg	Würzburg	2017	Warm temperate	25–30	500	Public open space	No
Chicago Riverwalk	Chicago	2016	Cold temperate	No data	17,000	Public open space	No
Tour de la biodiversité	Paris	2016	Temperate	2–4	170	Building	Yes
Bosco Verticale	Milan	2014	Warm temperate	20–35	1500–10,500	Building	Yes
Kö-Bogen II	Düsseldorf	2020	Warm temperate	125 cm in height	270	Building	No
Torre Guinigi	Lucca	13th century	Mediterranean	30–70	10,000	Building	No
79&Park	Stockholm	2018	Temperate	No data	8000	Building	No
Vietnam Pavilion	Milan	2015	Warm temperate	No data	115	Building	No
25 Verde	Turin	2013	Warm temperate	20–25	No data	Building	No
Inktpot	Utrecht	2004	Warm temperate	No data	No data	Building	No
Etaget	Stockholm	2017	Temperate	12–14	3000–6000	Building	No
Wohnpark Alterlaa	Vienna	1985	Warm temperate	No data	No data	Building	No
Hundertwasserhaus Wien	Vienna	1985	Warm temperate	No data	No data	Building	No
Hundertwasserhaus Taunus	Bad Soden	1993	Warm temperate	No data	No data	Building	No
Grüne Zitadelle	Magdeburg	2005	Warm temperate	No data	No data	Building	No
Calwer Passage	Stuttgart	2021	Warm temperate	No data	No data	Building	No
Carré Belge	Köln	2019	Warm temperate	No data	No data	Building	No
IKEA Vienna	Vienna	2021	Warm temperate	No data	1000–3000	Building	No
Skyline Plaza	Frankfurt	2013	Warm temperate	No data	No data	Building	No

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