**Almere Pampus - A Timber City steering towards a Nature-Inclusive Urbanism**

Honours Programme Master Report
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–
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[**Abstract**]

Cities are constructed with extractive, finite resources that put enormous pressure on global climatic conditions. The building and construction sector is responsible for 36 percent of the global energy demand and 37 percent of the carbon dioxide emissions worldwide. With the prospect of massive urbanization, the built environment will fundamentally contribute to a spike in global carbon dioxide emissions. This paper investigates an alternative: It researches the potential of turning cities into carbon sinks with emphasis on the reduction of embodied carbon dioxide emissions of cross-laminated timber. Localizing the supply chain and bridging the gap between urban planning and timber production allows the investigation of synergies between the forest and the city. This research tackles the dilemma of accelerated urbanization while decreasing C02 emissions in a research-by-design approach with a city development project as a case-study. The proposed transition from the commodification of timber to the holistic benefits of trees results in an integrative design of ecologic processes and urban dynamics. This paper suggests a framework to offset the embodied carbon dioxide emissions of cross-laminated timber by transcending the nature city dichotomy.

[**Keywords**] *embodied carbon dioxide, cross-laminated timber, carbon sink, timber supply chain, urban forests*

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## ***Part I: Introduction***

### *1.1 Embodied Carbon in the Construction Industry*

The building and construction sector are responsible for 36 percent of the global energy demand and 37 percent of the carbon dioxide emissions worldwide (United Nations Environment Programme, 2021). Considering that the carbon dioxide emission of a car that drives more than 2,500 kilometres equals the production of one ton of concrete reveals the tremendous impact the building industry has on global warming (United States Environmental Protection Agency, 2021).
In the context of growing urbanization across continents, there is a critical demand to decarbonize the construction industry to comply with the Paris Agreement from 2015 and limit global warming to 1.5, maximum 2 degrees Celsius by 2050 (United Nations, 2015). Pursuing climate change mitigation, the European Commission agreed in 2020 on the European Green Deal (United Nations, 2015). This agreement lays out a strategy to reduce the net greenhouse gas emissions to zero, making the European Union climate neutral by 2050 (United Nations, 2015). Both a transition towards a circular building sector and the decarbonization of the building industry play a major role in achieving these goals. Thus, besides the reduction of operational energy of buildings – a goal that is clearly stated in the European Green Deal, the embodied carbon emissions of the built environment need to decrease to head towards a sustainable building sector (Mohammed et al., 2013). While the emissions of operational energy are considered by building sustainability certificates, the emissions that are emitted during excavation and transport are however neglected in many green building certificates such as nearly zero-energy and low-energy buildings, and insufficiently valued in LEED and BREEAM certificates (Amiri et al., 2021).

### *1.2 Emergence of Cross-Laminated Timber in the Building Sector*

In the process of reducing carbon dioxide emissions and moving away from the use of fossil fuels, the utilization of bio-based materials could contribute to mitigate both phenomena (Organschi et al., 2016). In contrast with traditional building materials such as cement and steel, renewable materials are biodegradable and produced in a circular process. Mineral products like cement, steel, and glass produce high amounts of C02 emissions along the chain from the extraction of raw material to the supply on the construction site (Churkina et al., 2020). Bio-based materials such as timber not only generate considerably lower emissions in the production process but additionally absorb $CO_2$ from the environment and store it until the end of their lifecycle.
In comparison to other bio-based materials, wood has clear advantages such as its flexibility in use, renewable availability, and a long-standing knowledge of processing and manufacturing wood products. Due to its properties, cross-laminated timber (CLT) represents the most viable alternative to steel and concrete among mass timber materials (Anderson, 2020). While glued-laminated timber (GLULAM) is due to a different layering of timber lamellas primarily used for load-bearing elements, CLT is used for surfaces such as floors and walls.
Based on significant research on the utilization of CLT in the last 20 years, there is an accelerating development toward the application of this technology in the mid-to high-rise building sector. Whereas in 2012 the tallest wooden building was 32-meters high, the development reached a new milestone in 2019 with the completion of the 85m high Mjösa Tower in Norway (Harte, 2017; Leonard, 2022). Thus, the building sector encounters an increasing amount of engineered timber buildings. However, the utilization of CLT has rarely been extended to the planning of entire

districts in this material. One example is the Netherland´s first wooden neighbourhood in Amsterdam that will start the construction in 2025 (O´Sullivan, 2022). Yet, lacking any reference to the source of materials, flows, and the extended landscapes of production needed, it reveals a lack of synthesizing timber production and its flow with urban strategies that would prompt a reduction of embodied carbon emissions.

### *1.3 Literature Review*

Based on the CO2 storage capacity and the circularity of wood, the utilization of timber products has gained momentum in urban design and architectural research and practice. Churkina et al. (2020) suggest transforming cities into global carbon sinks to tackle the dilemma of accelerated urbanization while decreasing C02 emissions. Studies have been made to quantify the impact of timber cities on the reduction of C02 emissions (Organschi Architecture, 2016). Moe (2020) lays out that these reductions are calculated on the substitution of mineral-based materials and the embodied carbon emissions of timber products. Within the building industry and policymaking, there has been much attention to decrease the operational carbon emissions of buildings. The embodied emissions however are largely neglected. The Life-Cycle Assessment (LCA) is one of the few techniques that quantify the environmental impact of products, yet the assessment and the calculation remain complex and intricate. Hence, literature calls for an integration of embodied carbon into green building certificates (Amiri et al., 2021).
Further, enabling and fostering the large-scale application of timber requires a synthesis of timber production with urban planning strategies. Therefore, Ospina suggests combining networks of interdependencies and reciprocal influences of systemic thinking with the contextualization of design thinking that gives form to ideas (Ospina, 2018; Wandl, 2021). In Europe, CLT is mainly produced from C24 spruce – a wood species that is superior to C16 in strength and resilience (Levent, 2020). Research has been done to assess the suitability of locally grown wood species (Harte, 2017). However, the localization of CLT production has been focused predominantly on the technical requirements of native wood and has insufficiently investigated the creation of a circular material flow system. Furthermore, the potential that lies in the combination of the productive forest with the intrinsic climatic and social benefits of trees in urban settlements remains largely unexplored. To profit from these benefits, research needs to be specifically territorial to link regional environmental characteristics to spatial design (Wandl, 2021).

### *1.4 Research Question*

Based on the widely unexplored potentialities of the reduction of carbon dioxide emissions that lie at the intersection of systemic thinking and design thinking, this research shall explore the question: *How to decrease the embodied carbon dioxide emissions of cross-laminated timber for the construction of a district in bio-based materials by researching synergies between the production chain of wood, the forest, and the city?*
This research is situated in the context of the Amsterdam Metropolitan Area in the Netherlands and deals with current territorial issues such as decreasing C02 emissions while providing 200.000 new apartments by 2030 (Vermeulen, 2019). This exploration is in line with the regional Green Deal Timber Construction proclaiming that from 2025 on at least 20% of all new construction must be built in timber (AMS Institute, 2021).

### *1.5 Approach*

This research tackles dilemmas of climate adaptation in urbanized areas that can be characterized as wicked problems. Rittel and Webber coined the term wicked problems in 1973 as dealing with issues that do not have a finite solution but address the notion of uncertainty and thus, must be approached in a multi-dimensional way. Localizing food production at times of land scarcity and reducing CO2 emissions, while building more housing are just two examples. Focusing on the latter, the issue shall be approached by a synthesis of research and design that allows counterintuitive thinking and supports the production of knowledge on wicked problems. The research-by-design approach is complemented by a case study (Yin, 1984) that embeds the research in a contextual investigation of ecological, environmental, and urban dynamics. Here, the research bridges the gap of the dichotomous relation of the city and its productive hinterland by juxtaposing and synthesizing urban and ecological processes.

The main research question is addressed by analysing three different subtopics, namely the production of timber in the urban periphery, the potentialities of timber production in the city and the underlying logic of the CLT supply chain. The analysis of the CLT supply chain is addressed with the following research sub-question: What spatial and infrastructural conditions are required for the production of CLT? The topic of timber production in the urban periphery is addressed with the following research sub-question: How to create different typologies of productive forests as spatial units embracing various characteristics of trees? The topic of timber production in an urbanized area is addressed with the following research sub-question: How to complement timber production with urban expansion while profiting from the multiple benefits of tree growth?

### *1.6 Methods*

This research draws on a mixed method approach to reach the project´s aim of proposing a strategy to build a whole district exclusively in bio-based materials with an emphasis on the reduction of embodied carbon of CLT.

A review of existing literature published on core topics such as the decarbonization of the built environment, typologies of urban greening, and the characteristics and the production of CLT formed the base of the project´s theoretical framework. Scientific articles and reports have been selected according to their relevance. The outcome of the review constituted the foundation on which the design proposal was based.

The analysis of the infrastructural and spatial conditions for the localization of the CLT supply chain is preoccupied with the method of mapping. The required information has been gathered by reviewing literature and design projects and collecting data from Geographic Information System Mapping (GIS).

Interviews with experts from a CLT production company in Germany, a timber engineering company in the Netherlands and the Dutch Ministry of Agriculture, Nature and Food Quality have been proven to fundamentally influence the research. The information gathered during the interviews has been beneficial to confront the theoretical knowledge with practical experience. The chosen actors give a glimpse into the diversity of stakeholders included in the process of synthesizing urban planning strategies with material production.

The research and design part of the project has been oriented specifically towards the case study of Almere Pampus. The location under investigation is located in the Metropolitan region of Amsterdam in the Netherlands. Almere Pampus will be developed to accommodate 30.000 new dwellings until 2050 with the ambition to become a role model in social and environmental sustainability (Huijding et al., 2021). Almere Pampus has been chosen as a testing ground due to the ambitious development plans of the city and stakeholders that pursue the creation of an innovative, sustainable, and healthy district.

# ***Part II: Toward a New Cross-Laminated Timber Supply Chain***

## *2.1 Introduction*

This section seeks to outline potential changes in the current CLT supply chain in the Netherlands with the ambition to decrease embodied carbon dioxide emissions and thus contribute to a development toward more sustainable building materials. Therefore, the focus shall be first on an analysis of relationships, interdependencies, and succession of the different steps entailed in the supply chain of CLT. Here, the analysis will draw on references where a sustainable chain from timber production to the construction on site is already established. Further, the outcomes will be compared to the current CLT production cycle in the Netherlands. Localizing the investigation with the insights of the previous analysis shall allow identifying potentialities to further reduce the environmental impact of timber as a building material. This section will culminate in a proposal for a new CLT supply chain in consideration of the specific territorial conditions of the area under investigation. Different layers shall be examined that proved to fundamentally inform the supply chain such as infrastructural conditions and land-use patterns.

## *2.2 Analysis of the CLT Supply Chain*

The potential of timber to contribute fundamentally to the decarbonization of the built environment is largely acknowledged and has received increased interest. Yet, to fulfill its promise as a mitigator of climate change, it is crucial to work toward a sustainable supply chain that reduces the embodied carbon dioxide emissions (Muszynski et al., 2017). Leading countries in the production and application of CLT products are Germany and Austria which shall serve as case studies in the following analysis (Muszynski et al., 2017). The supply chain of CLT can be summarized in five primal steps: resource extraction, production of sawn wood, production of CLT elements, assembly on site, and reuse of CLT elements (Vermeulen, 2019). Between every step, the product is moved to the following site. Thus, the reduction of transport becomes a topic of major concern (see fig. 01).

Here, an interview with the manager of HSB Berga, a leading German CLT producer, gave insights into the interdependencies and relationships of the different processes. Around 100 – 150 km between the forest and the sawmill proved to be economically feasible and thus entails an incentive to utilize locally grown wood (see fig. 03). The transformation of round wood into sawn wood produces cuttings in a ratio of 1.8. (R. Steindl, personal interview, 2022). The residual parts of the tree are used for firewood, production of pallets, or biomass which minimizes waste in the production cycle. According to the interviewee, close proximity of the sawmill to the CLT factory is essential to ensure seamless production. Here, sawn wood is glued and pressed together to prefabricated CLT and GLULAM elements. Finally, every product is custom-made in the desired shape with openings for doors, windows, and pipes that allow fast and dry assembly on the construction site (Vermeulen, 2019).

Besides the proximity to a sawmill, the location of the CLT factory must fulfill several logistic and strategic purposes such as a short distance to the market and favorable infrastructural conditions (R. Steindl, personal interview, 2022). A location outside a city with easy highway and railway access meets these requirements. The prefabricated CLT elements then travel to the contractor, respectively the construction site where they are assembled. After their lifespan which strongly depends on the typology of the building and its specific function, the element can be reused in various ways. As CLT is a highly engineered wood product with long durability, the optimal function is to reuse it for the very same purpose in a building. If the CLT element does not fulfill the building standards anymore, it can be downcycled to veneer, insulation board, or biomass production. As

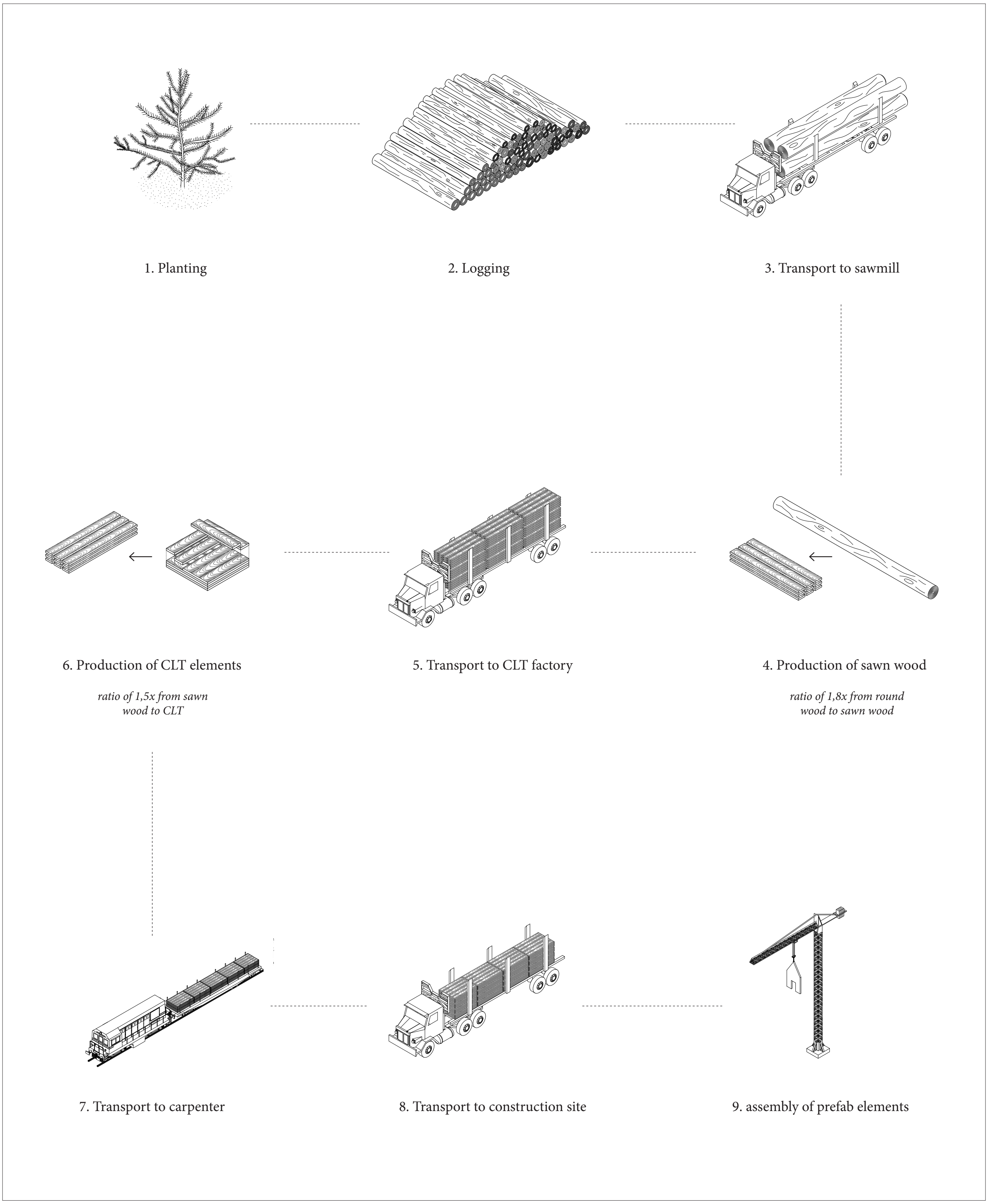



*fig. 01: timber supply chain diagram from resource extraction to the construciton on site*

timber releases the captured $CO_2$ in this process, the ambition is to maximize the lifespan of the product (Vermeulen, 2019).

According to the interviewee there are potentials to further reduce the ecological footprint of the CLT supply chain. One suggestion is to substitute chemical adhesives to glue the timber lamellas, with adhesives based on melanin or to connect the layers mechanically. This would allow facile disassembly and prevent the emission of toxic gases during combustion.

### *2.3 Current State of the CLT Supply Chain in The Netherlands*

The utilization of CLT as building material in The Netherlands has recently gained momentum. More specifically, the use of timber and hybrid structures in the high-rise sector is becoming an attractive and sustainable option. The Patch22 (30 m, full timber) in Amsterdam and The Dutch Mountains (130 and 100 m, timber hybrid) in Eindhoven are two examples that are representative of this development (FRANTZEN et al architects., 2017; Vermeulen, 2021) . Until now, the increasing demand for CLT is entirely met through imports (P. Buffing, personal interview, 2022). The lack of a CLT factory in The Netherlands can be traced back to that fact. In 2021, 95 % of softwood products (such as CLT) have been imported, with Sweden and Germany being the biggest suppliers (Institute for Forestry, Forest Products and Services, 2021). As a consequence, there are very few sawmills in The Netherlands that constitute a fundamental part of the CLT supply chain.
One reason for the strong dependence on foreign wood is that timber production is not prioritized in the Netherlands. Trees mainly serve the purpose of increasing biodiversity, mitigating climate change, and recreation (P. Buffing, personal interview, 2022). However, The Green Deal Timber Construction signed in 2021 by 32 municipalities in the Metropolitan Region of Amsterdam engendered a new discourse on localizing timber production. With the prospective increase of CLT consumption, there are plans to build the first CLT factory in the MRA region (Amsterdam Institute for Advanced Metropolitan Solutions, 2021).
One possibility to increase timber production without neglecting the prioritized purposes mentioned above would be to create hybrid forest typologies. Here, the forest would not merely serve a single purpose such as recreation or increasing biodiversity but embrace the various benefits of tree growth. Hence, localizing the CLT supply chain would not only make The Netherlands less dependent on foreign countries but also entails the potential to create awareness for the compelling transition toward a sustainable and nature-inclusive future. Another added value is the reduction of embodied C02 in timber that is inherent in shortening transport routes.

### *2.4 Design of a New CLT Supply Chain*

The first step in planning the development of the district of Almere Pampus exclusively in bio-based materials with emphasis on CLT is to secure that the timber supply meets the demand. Localizing the CLT production is an effective way of guaranteeing constant access to construction wood while reducing the embodied C02 emissions. Based on the previous analysis, the following investigation proposes a CLT supply chain that is entirely situated in The Netherlands and suits the demand to build Almere Pampus in CLT. Therefore, the specific infrastructural and logistical conditions of the area under investigation have been dissected to inform the choice of a site for a CLT factory.
In the beginning, two primal premises have been outlined that serve as a starting point in the analysis of a suitable location for the factory. Firstly, access to the resource and secondly proximity to the market. A circle with a 50 km radius has been drawn around the center of Flevoland that will serve as a timber


*fig. 02: analysis of logistical and infrastructural conditions for the erection of a CLT-factory*

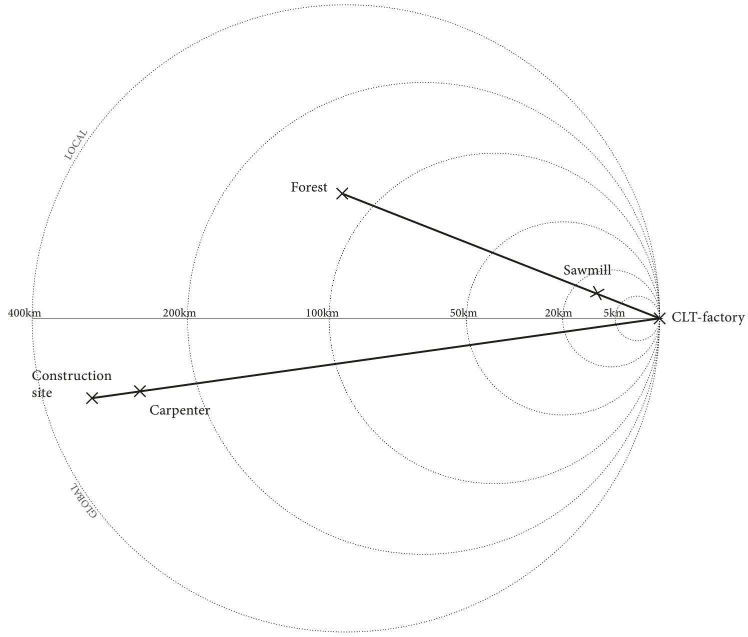



*fig. 03: distances of timber supply chain in Germany*

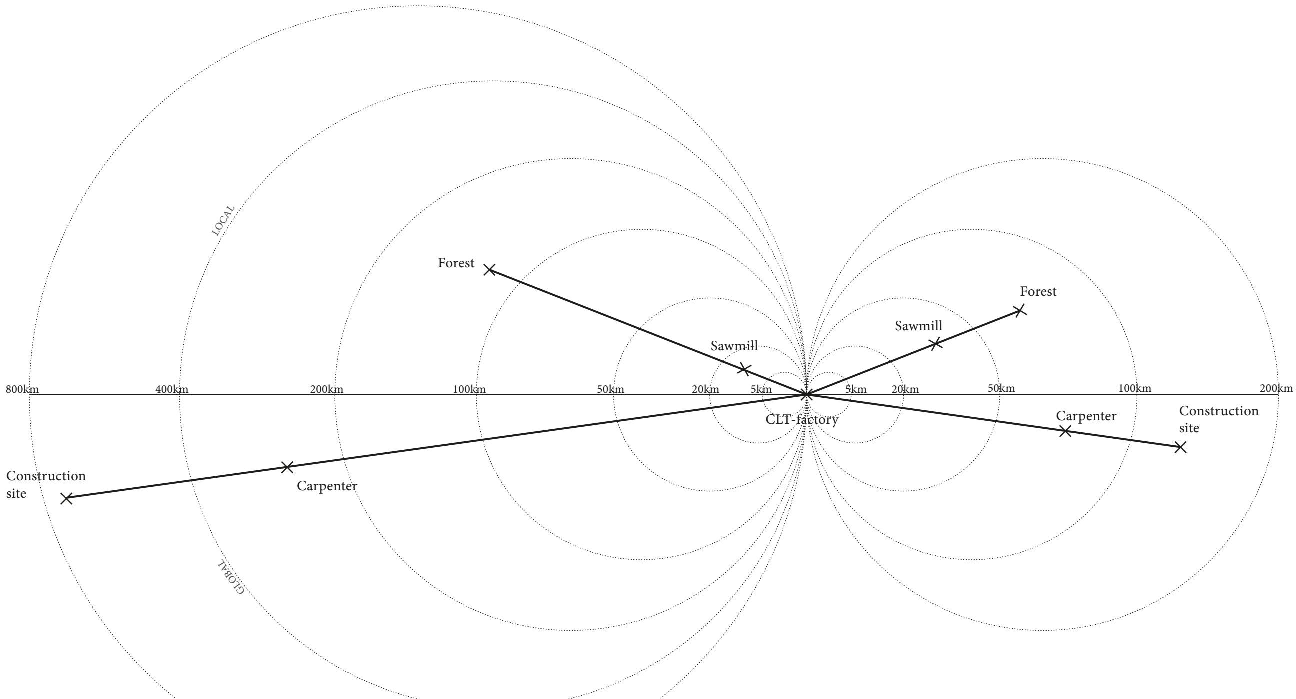



*fig. 04: comparison of timber supply chain in The Netherlands before and after the erection of a CLT-factory*

production hub in the future scenario (see fig. 02). Focal point of this study is the availability of CLT for the development of Almere Pampus. The area included in this investigation was based on contemplating regions with high prospective growth to secure a demand that goes beyond the construction of Almere Pampus such as the Metropolitan Region of Amsterdam (City of Amsterdam, 2023). In a next step, the infrastructural network of the area has been analyzed with emphasis on accessibility by truck and train. Highways, primary roads, and the railway network have been extracted to render a map that clearly highlights different concentrations of transport ways. Areas, where infrastructural hubs coincide with medium-sized cities, are considered favorable sites for a CLT factory as they constitute attractive locations for employees. To further narrow down the potential locations existing sawmills have been highlighted. Acknowledging that a CLT factory would require a new sawmill that can process roundwood to sawn wood in high quantities, a relatively high concentration of sawmills is conceived as an indicator for a beneficial location.

The analysis points out two potential sites that fulfill the required conditions for the implementation of a CLT factory. The area northwest of Amersfoort benefits from its location between Amersfoort and Hilversum and thus ensures optimal accessibility. The second choice is situated north of Apeldoorn and profits from existing sawmills in close proximity.

Comparing the existing CLT supply chain in The Netherlands with the new proposal renders visible the reduction of transport that strongly impacts the embodied CO2 emissions (see fig. 04). The distance traveled from the site of resource extraction to the construction on site can be reduced by approximately two-thirds.

### *2.5 Conclusion*

This chapter has been primarily preoccupied with revealing the potentials to reduce the embodied CO2 emissions of timber by analyzing and comparing the CLT supply chain of a best-practice reference to the production cycle in The Netherlands. As the single steps of processing the resource from logged wood to CLT are already highly efficient, the reduction of transport entails the highest potential of decreasing the embodied CO2 emissions. Therefore, this paper suggests localizing CLT production in The Netherlands and establishing a sustainable supply chain. The analysis of a potential location for a CLT factory draws on recent interest from the municipalities of the MRA. It can be considered as a starting point addressing the fundamental aspects that inform the search for a suitable location. Besides, this chapter laid out reasons for the dependence on imports of wood products that are much more profound than the sole erection of a CLT factory. They are deeply embedded in the politics of regulating forests that prioritize biodiversity and recreational purposes. Therefore, the following chapters investigate hybridized forest typologies that transcend the current mono-functional use and lay the groundwork for localizing the supply chain while benefitting from the multiple benefits of trees.

## *Part III: Typologies of Productive Urban Greening*

### *3.1 Introduction*

### *3.2 The Productive Urban Forest*

*3.2.1 Description and Overview of Scenarios*

*3.2.2 Forest as Carbon Sink*

*3.2.3 The Economic Forest*

*3.2.4 The Ecologic Forest*

*3.2.5 Conclusion*

### *3.3 The Hybridized City Forest*

*3.3.1 Description and Overview of Scenarios*

*3.3.2 City as Carbon Sink*

*3.3.3 The Economic Forest*

*3.3.4 The Ecologic Forest*

*3.1 Introduction*

As concluded in the previous chapter, the extension of the timber production capacities necessitates a diversification of forest typologies to embrace their holistic benefits and reject the commodification of trees. Therefore, this chapter investigates the potential of hybrid greening typologies in different contextual situations. The analysis departs from the suggestion of turning Flevoland, the center of agricultural production in The Netherlands into a green lung with different typologies and densities of trees. This possibility is rooted in the unique history of Flevoland and considers recent developments.

Flevoland, well-known as the biggest artificial island in the world is the result of large-scale land reclamation efforts in the 1960s (Schaap et al., 2011). Due to this land transformation and its location of 4 meters under sea level, the area is prone to subsidence that puts agricultural production at risk. Flevoland is already suffering serious issues of subsidence because of the shrinking peat soil (De Vries and Walvoort, 2018). Although peat soil contains nutrients that are favorable for the growth of various crops, the inherent drainage is one of the main reasons for subsidence (Finch, 2014). Trees however can accommodate in shallow peat soils and therefore tackle the danger of subsidence (Vanguelova et al., 2018). Hence, this paper bluntly explores the potentialities that lie in this vast territory to mitigate climate change by transforming it into different typologies of timber production.

The design framework is structured into two different typologies of urban forest, namely The Productive Urban Forest and The Hybridized City Forest (see fig. 05). Within each typological exploration, this research considers three different scenarios named The Ecologic Forest, The Economic Forest and Forest/City as Carbon Sink. These scenarios are further detailed into schemes that represent their temporal succession from 2023 to 2033 and 2053.

The two typologies of urban forest are situated in different contexts that reflect certain degrees of urbanity in Flevoland and Almere. The first site is located in the urban periphery where large-scale plantation patterns are tested in one spatial unit. In this site scenarios of productive urban forests shall be tested. The second site is in Almere Pampus and successively blends with the urban development of the district. Here, scenarios of hybridized urban forests shall be investigated.

***3.2. The Productive Urban Forest***

***3.2.1 Description and Overview of Scenarios***

The scenarios of the productive urban forest focus on different logics of tree growth accentuating the diversity of forest typologies. More specifically, the following research renders forest typologies as complex ecosystems that inhere the potential to perform toward specific benefits. Forest management including planting layout, planted species, rotation cycle, and infrastructural requirements are of major interest. For matters of simplification, clearings are not taken into consideration knowingly that they constitute an important aspect in the management of forests. The area around Hosterwold which is the largest deciduous forest in the Netherlands is taken as a testing ground (Hotspotholland, 2022). Initially, the forest is composed of the English Oak and European Beach, and predominantly the White Poplar. It is surrounded by agricultural fields and adjacent to the town of Zeewolde (see fig. 06).

**2033** In the first scheme that depicts the area in 2033, the forest has been divided along existing urban axis into three different typologies. The different types are named Ecologic Forest, Economic Forest, and Carbon Sink Forest, representing the most important benefits of tree growth (see fig. 07). The Ecologic Forest is the most natural typology that accommodates the highest diversity of tree species and requires least management.

With the prospect of accelerating decar-

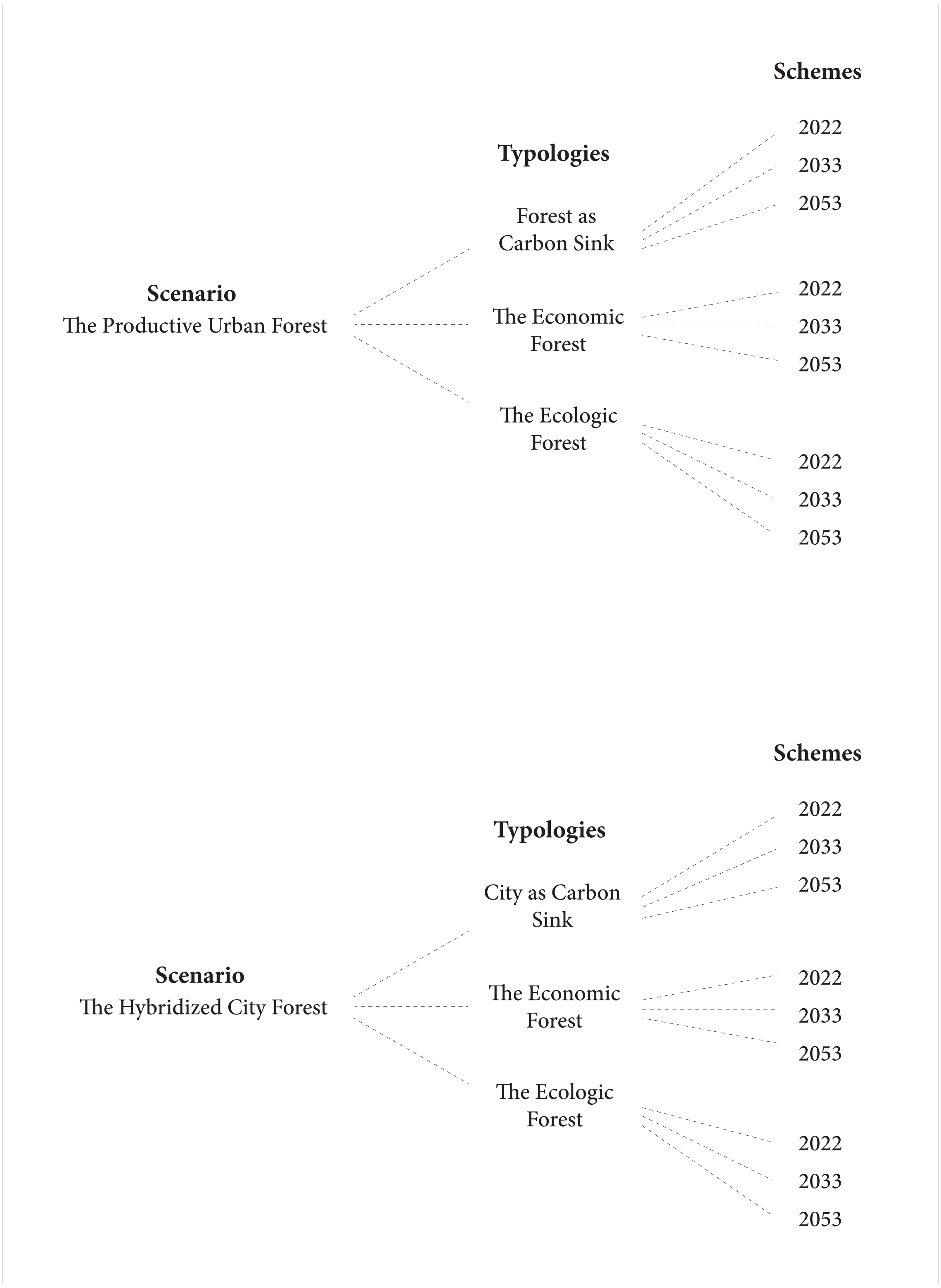



*fig. 05: design framework consisting of scnearios, typologies and schemes*

*fig. 06: The Productive Urban Forest, 2023*

*fig. 07: The Productive Urban Forest, 2033*

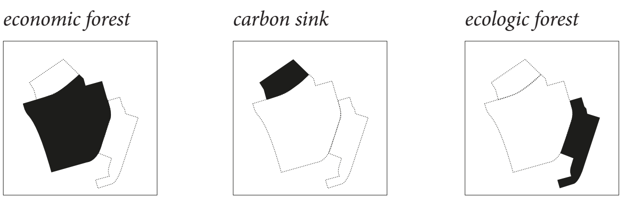
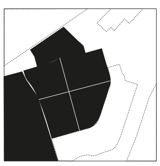
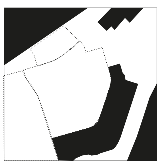


*fig. 08: The Productive Urban Forest, 2053*



bonization of the built environment and the intrinsic increasing demand for CLT, the Economic Forest is designed to produce the highest yield of coniferous timber. In 2033, the first CLT factory in The Netherlands is expected to be operating which guarantees in combination with the efficient planting layout and rotation cycle maximal availability of CLT.
The Carbon Sink is a mixed forest composed of coniferous and deciduous trees selected according to the highest carbon sequestration capacity. Besides the C02 absorption of trees, emphasis is here on activating and maximizing the carbon storage capacity of the under-canopy layer and the soil.

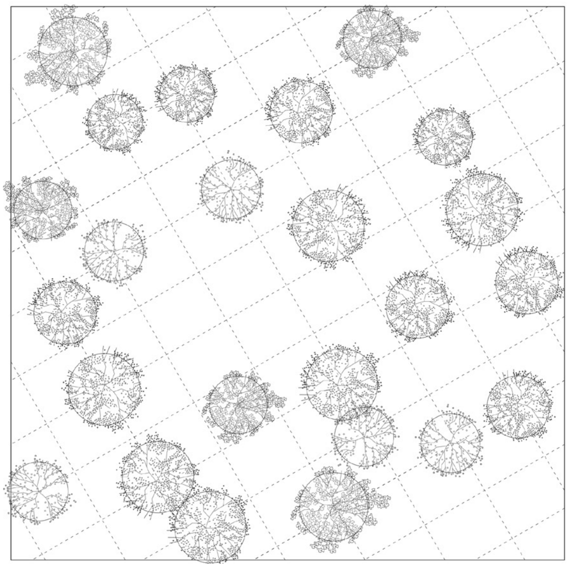
**2053** In the second scheme that simulates the state of Hosterwold and its surroundings in 2053, the different forest typologies expand beyond the boundaries of the existing forest and populate the adjacent agricultural fields (see fig. 08). The 30-year time horizon between the current state and the last scenario stems from the average time of one rotation cycle (Lindbladh et al., 2022). Moreover, Almere Pampus is expected to be fully erected in 2050, which serves as a case study project to synchronize timber production and urban planning (Gemeente Almere, 2021). In the context of increasing awareness for the integration of economic incentives with sustainable measures, this scenario speculates on the increasing importance of carbon benefits (Pope and Vasallo, 2019) . Therefore, a mixed typology emerges from the Carbon Sink and the Economic Forest accentuating the value of trees in the mitigation of the greenhouse gas effect and atmospheric pollution.
In the following, each typology shall be further examined in relation to structure, composition, and development of the forest. The written analysis shall be complemented by explanatory drawings that facilitate the presentation of the scenarios.

### *3.2.2 Forest as Carbon Sink*

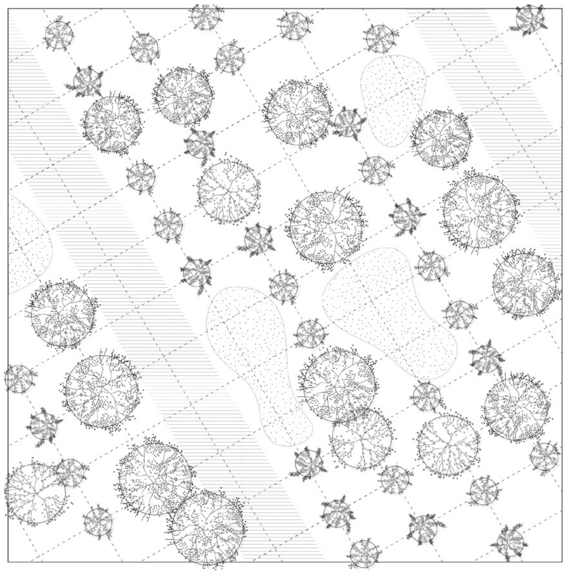
The Kyoto Protocol first recognized the importance of the "protection and enhancement of carbon sink and reservoirs" for the reduction of greenhouse gas emissions from the atmosphere (Robertson and Loza-Babuena, 2004). Overall, carbon ecosystems that include forests, grassland, and the aquatic system have accounted for the absorption of about one-third of anthropogenic carbon emissions during the last 50 years (Pan et al., 2011). Specifically, forests, which constitute the largest terrestrial carbon sink have great effect on the carbon cycle (Zhou, 2015; Yousefpour et al., 2018). The typology Forest as Carbon Sink builds on this very capacity and maximizes the amount of sequestrated carbon.

**2033** Firstly, a planting grid is imposed on the existing layout of the forest Hosterwold that reflects tree species that shall densify the forest prospectively. The tree species are chosen according to the highest carbon absorption capacity and their resilience under the given territorial and climatic conditions. Several characteristics have proven to increase the potential of high carbon sequestration such as fast-growing, native, and large-canopy trees. However, a mixed forest that is stable against disturbances makes a more effective carbon sink than a monoculture composed of trees with the highest carbon sequestration rate (Jandl, 2006). Taking all these influences into consideration, the existing species of White Poplar and English Oak that count to the most productive sequesters shall be complemented by fast-growing coniferous species such as Douglas Fir and Scots Pine (see fig. 10) (Pütsep, 2021). The planting grid of 2,5 x 2,0 m (Ontario Ministry of Natural Resources, 1995) results in 2000 trees per hectare excluding essential infrastructural components (see fig. 09).

**2053** Besides the storage of forest biomass carbon that is absorbed by trees, the constitution of the soil plays a fundamental role in the



*2023*



*2033*

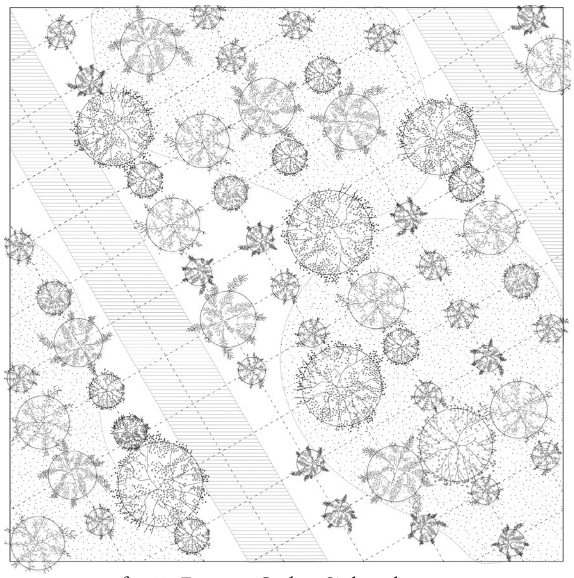


*fig. 09: Forest as Carbon Sink - schemes*

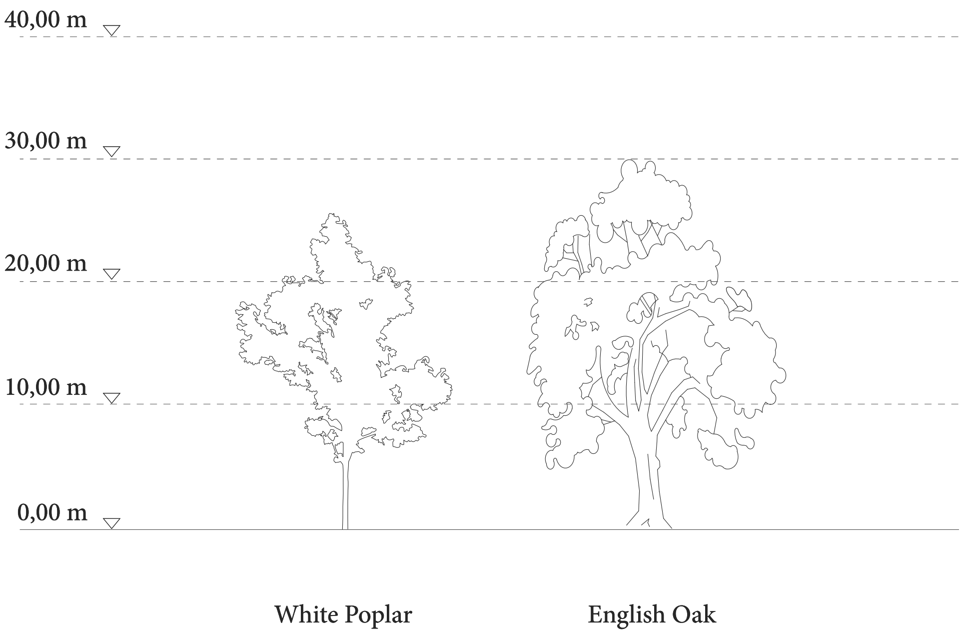
*2053*

*white poplar*

*english oak*

*douglas fir*

*scots pine*



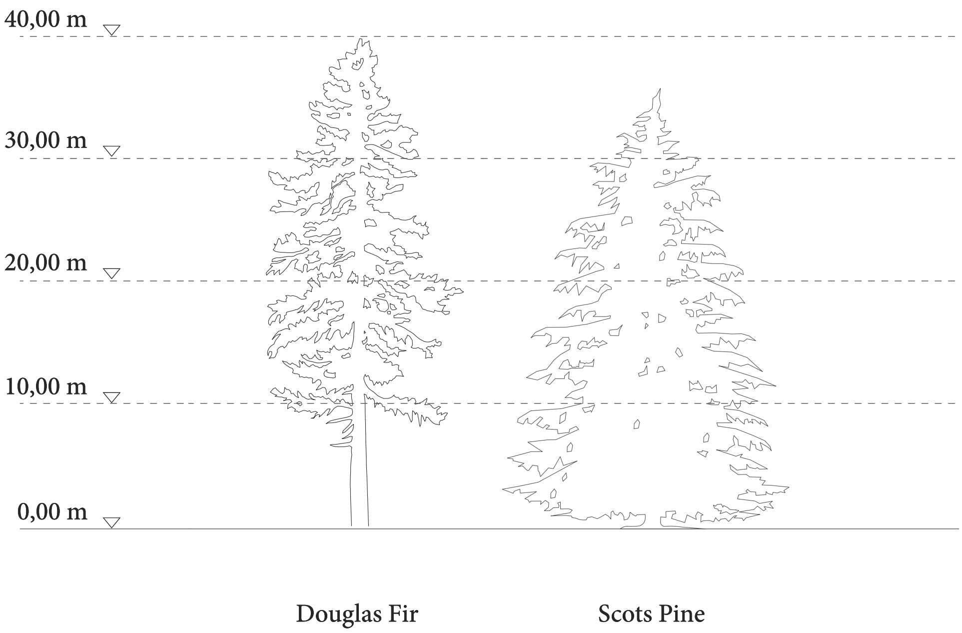




*fig. 10: Forest as Carbon Sink - tree species selection*

carbon stock of the forest ecosystem. The soil carbon stock contains more than two-thirds of the entire terrestrial carbon captured in the forest ecosystems (Lal, 2005). Especially in the transformation of degraded agricultural soil to forest plantation lies great potential. The conversion of the adjacent agricultural fields into forests that begin in 2053 results in an increase of soil carbon stock by 20-50% (Lal, 2005). In this typology, the rotational cycle is chosen to meet specifically the purpose of the highest carbon sequestration. Poplars for instance have an optimal rotation age of 11 to 14 years depending on the location and density (Abedi et al., 2018). Studies have shown that the introduction of carbon benefits that are part of the scenario 2053 extend the rotation age (Abedi et al., 2018). "The higher the value of the carbon benefits the longer the gestation period" (Kula and Gunulay, 2011). The practice of selective logging is applied to create the least interference with the existing forest layout and in consideration of the logics of communal tree growth such as the protection of seedlings by larger trees.

The Forest as Carbon Sink conveys the complexity of the interdependencies of the forest ecosystem. It reveals fundamental aspects to create and manage an effective carbon sink. Further research and the subsequent implementation shall support the ambition of maximizing the carbon sequestration capacity

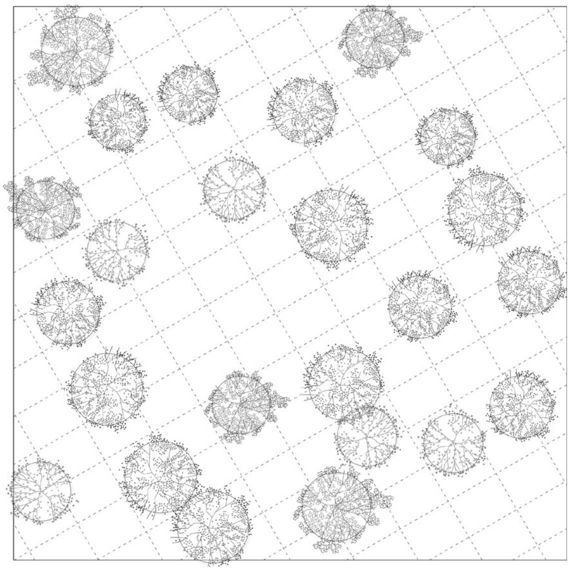
### *3.2.3 The Economic Forest*

The use of timber as a building material has experienced significant proliferation throughout the last decade (Svatoš-Ražnjevi´c et al., 2022). This is primarily based on its carbon storage capacity and renewable nature. The introduction of CLT as solid wood panels brought new momentum to timber constructions, especially in the high- to midrise sector. The Economic Forest is designed with the primal premise of producing the highest yield of timber satisfying the increasing demand for CLT.

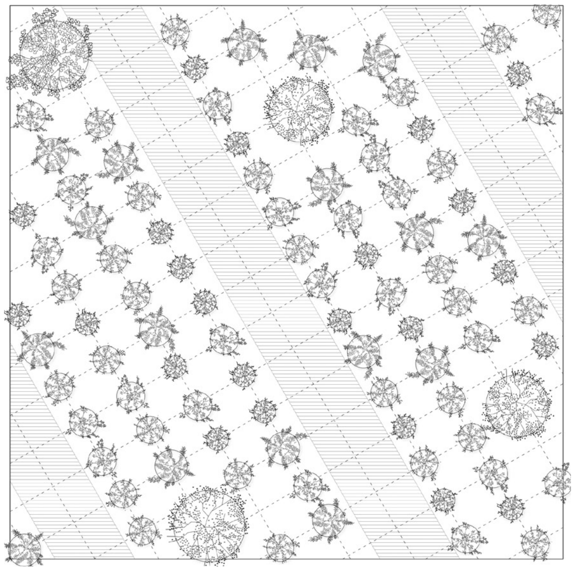
**2033** Currently, CLT is mainly produced from softwood species, predominantly from Norway Spruce. This is complemented by the fabrication of a small amount of Scots Pine, European Larch, and Douglas Fir (Svatoš-Ražnjevi´c et al., 2022). Hence, the typology of the Economic Forest is aiming at consecutively transforming the existing deciduous forest of Hosterwold into a coniferous forest. Therefore, the aforementioned species are used which suit the production of CLT (see fig. 12). This conversion is expected to be carried out until 2033. Due to the small canopy of coniferous trees and the aimed efficiency, the forest is planted in a dense grid of 1,5 x 2,0 m (Ontario Ministry of Natural Resources, 1995). This results in 3300 trees per hectare excluding the extended infrastructural space (see fig. 11).

**2053** The rotation cycle of Norway Spruce extends the time horizon of the scenarios. With the intention of an efficient CLT production, the rotation time can be determined at around 45 years (Lindbladh et al., 2022). Therefore, the scenario in 2053 merely shows minor changes and primarily tracks the growth of the existing trees. The speculative introduction of carbon benefits in 2053 and the subsequent coalescence of the typologies of Forest as Carbon Sink and the Economic Forest results in a transformation into a mixed forest. Besides increased resilience, this scenario draws on the existing potential of concurrently using hardwood species for CLT. This shall lead to a diversification of available CLT products that can be used according to their specific material properties.

The development of the Economic Forest is strongly dependent on external factors such as future research on CLT and potential economic incentives. As these factors underlie a different time frame than the growth of a forest, far-sighted planning is mandatory that prioritizes the holistic nature of the ecosystem.



*2023*



*2033*

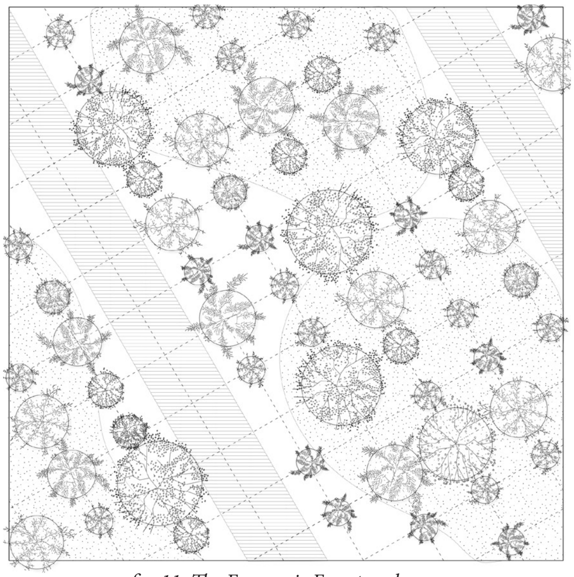


*fig. 11: The Economic Forest - schemes*

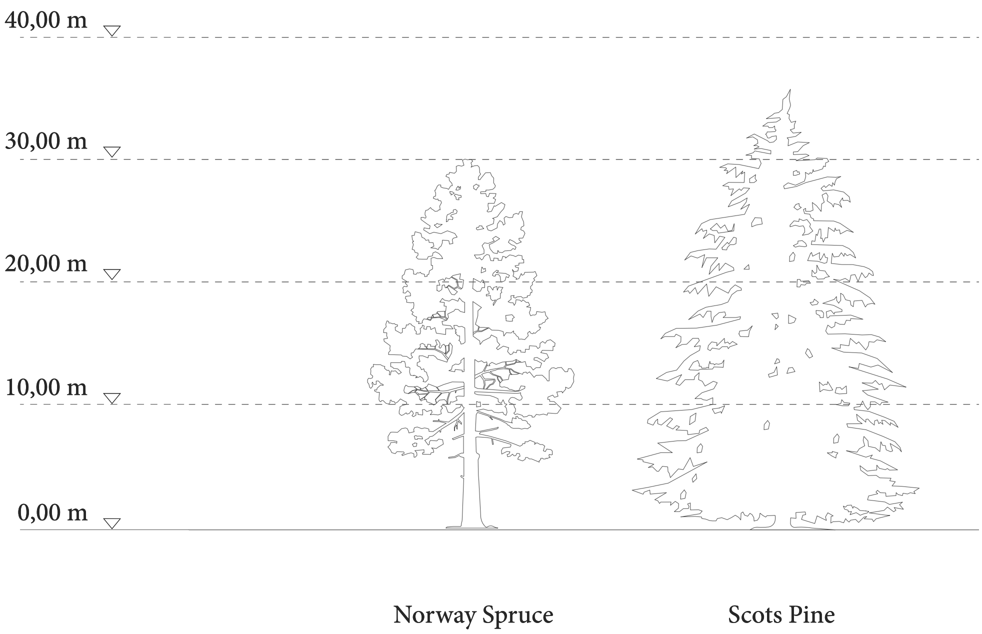
*2053*

*norway spruce*

*scots pine*

*douglas fir*

*european larch*



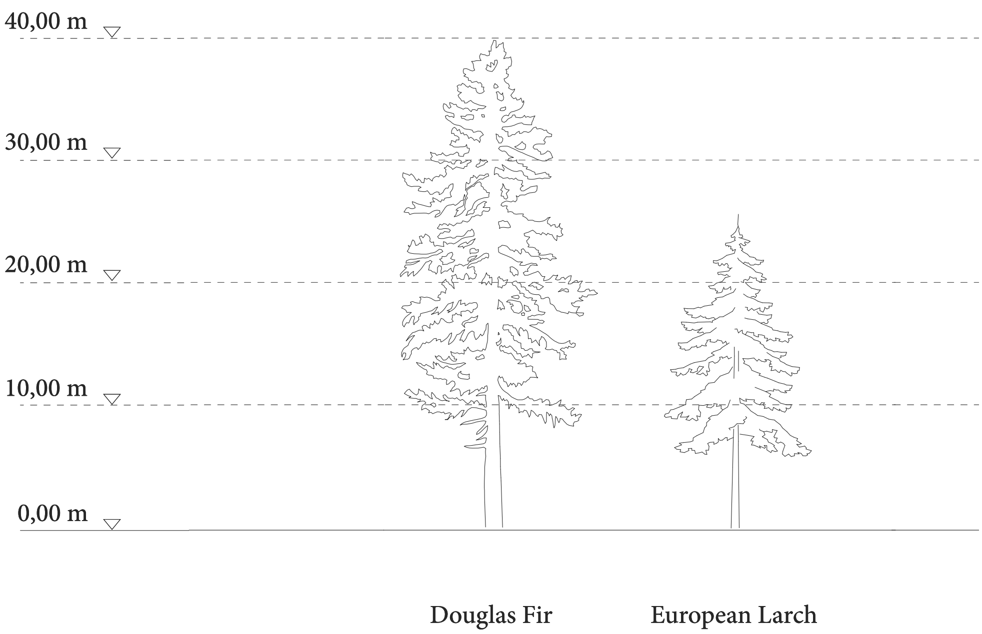




*fig. 12: The Economic Forest - tree species selection*

### *3.2.4 The Ecologic Forest*

It is widely acknowledged that mixed forests provide more biodiversity than their monocultural counterparts. This results in advantages in the provision of material, carbon sequestration, and regulation of disturbances (Jacktel et al., 2018). It is not wrong to posit that "most forests are naturally mixed and species diverse" (Pretzsch et al., 2017). Yet, one must distinguish between man-made, secondary forests and unmanaged native forests. The diversity of the former is substantially lower and leads to greater simplicity of the ecosystem (Pretzsch et al., 2017). In most forest ecosystems the majority of the species inhabit the under-canopy layer. However, this investigation shall largely focus on different tree species as they encompass the foundation species of the ecosystem due to their size and longevity (Pretzsch et al., 2017).

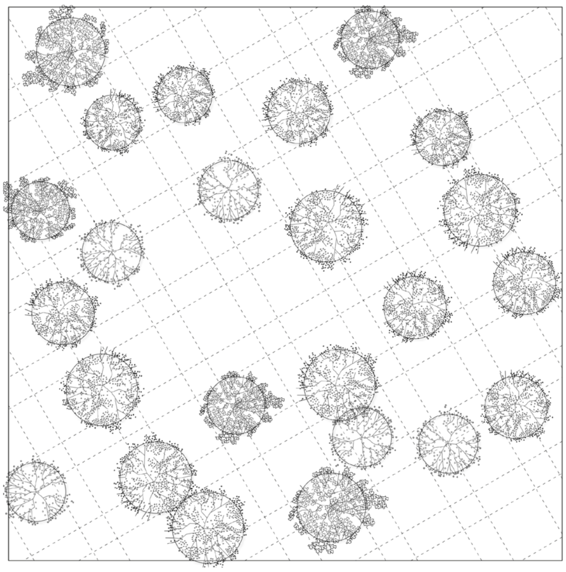
**2033** The Ecologic Forest is preoccupied with the premises of increasing biodiversity, creating wildlife habitat, and improving resilience against biotic and abiotic disturbances. Therefore, it is designed with the ambition to mimic a natural forest. In its initial composition, this typology encompasses six different tree species. The existing species of White Poplar, English Oak, and European Beech shall be complemented by the coniferous species of Norway Spruce, Scots Pine, and Douglas Fir (see fig. 14). Research has proven that "the magnitude of ecosystem processes increases decremental with the number of species" (Jacktel et al., 2018). The planting grid of 2,0 x 2,5 m is overlaid with a slightly shifted grid with the same measures (see fig. 13). Besides the resulting natural appearance of the forest, this layout enhances the processes among the different species. The most important interactions among different individuals are competition, competitive reduction, and facilitation. The random pattern leads to a layout in which each tree has at least two heterospecific neighbors that intensify these interactions (Jacktel et al., 2018). Moreover, the irregular layout produces gaps in the canopy that allows light to penetrate and the under canopy consisting of bushes, shrubs, and grass to flourish.

**2053** Until 2053 the ground layer of the forest is expected to be largely covered. The access to this typology is based on the human scale which conveys the reduction of interferences and management emphasizing the natural composition of the forest. One of the difficulties pertaining an uneven-aged mixed forest is determining the rotation of the trees. Uneven-aged stands consist of three or more age classes, varying in height, age, and diameter (Even-aged Versus Uneven-aged stands, 2017). As a result, the rotation time of each type can only be specified in the very specific contextual conditions supported by data that transcends the limited frame of this research (Pretzsch and Forrester, 2018).

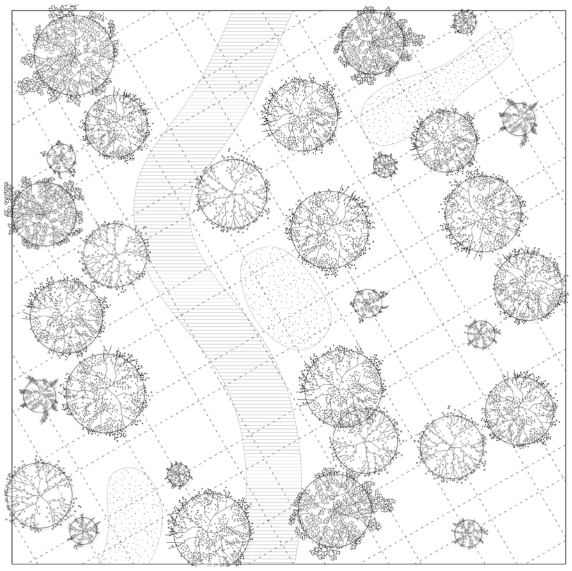
The Ecologic Forest is a typology that resembles a natural forest in its composition and management. Distancing from the commodification of timber and embracing the holistic benefits of trees such as carbon absorption, resilience, and the creation of biodiversity leads to a different forest composition. Although the advantages of mixed forests are largely acknowledged, the majority of forests in Central Europe can be still conceived as monocultures (Pretzsch et al., 2017).

### *3.2.5 Conclusion*

The previous analysis clearly highlights the importance of the composition and management of the forest. The three typologies dissect different approaches toward the forest ecosystem with the objectives of carbon sequestration, timber production, and high ecologic value. Each typology is a simplification that outlines specific characteristics aiming at the purposes mentioned above. It is important to add that these benefits do not occur exclusively in their respective typology.
Potentially, in a next step the typologies would be mixed to investigate the creation of synergies. Therefore, further research is critical to



*2023*



*2033*

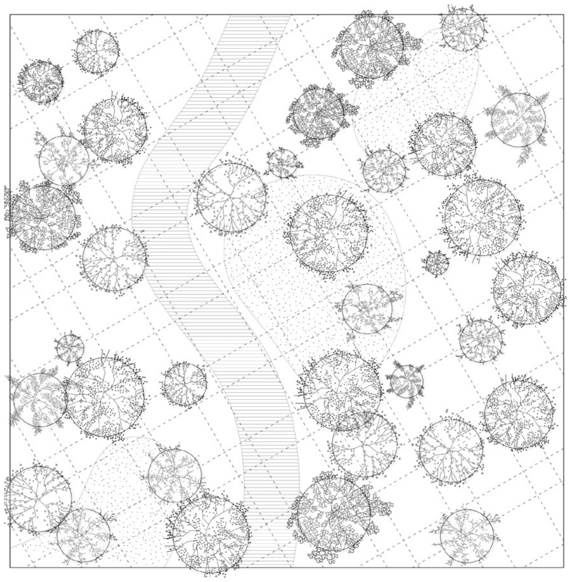


*fig. 13: The Ecologic Forest - schemes*

*2053*


*white poplar*

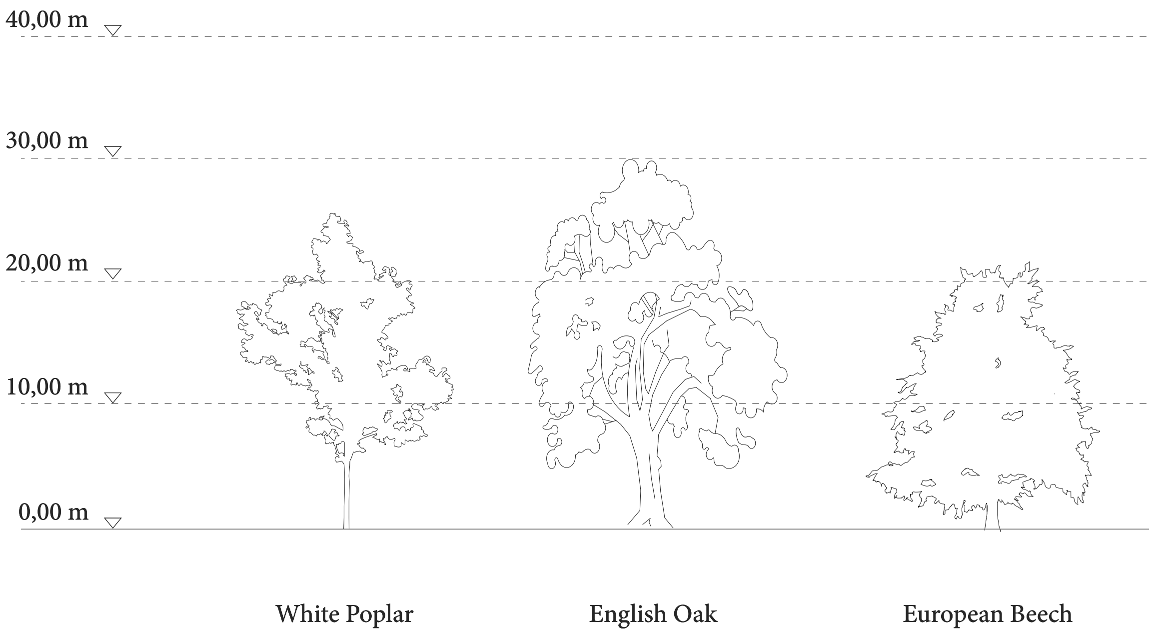

*english oak*


*european beech*


*norway spruce*


*scots pine*


*douglas fir*



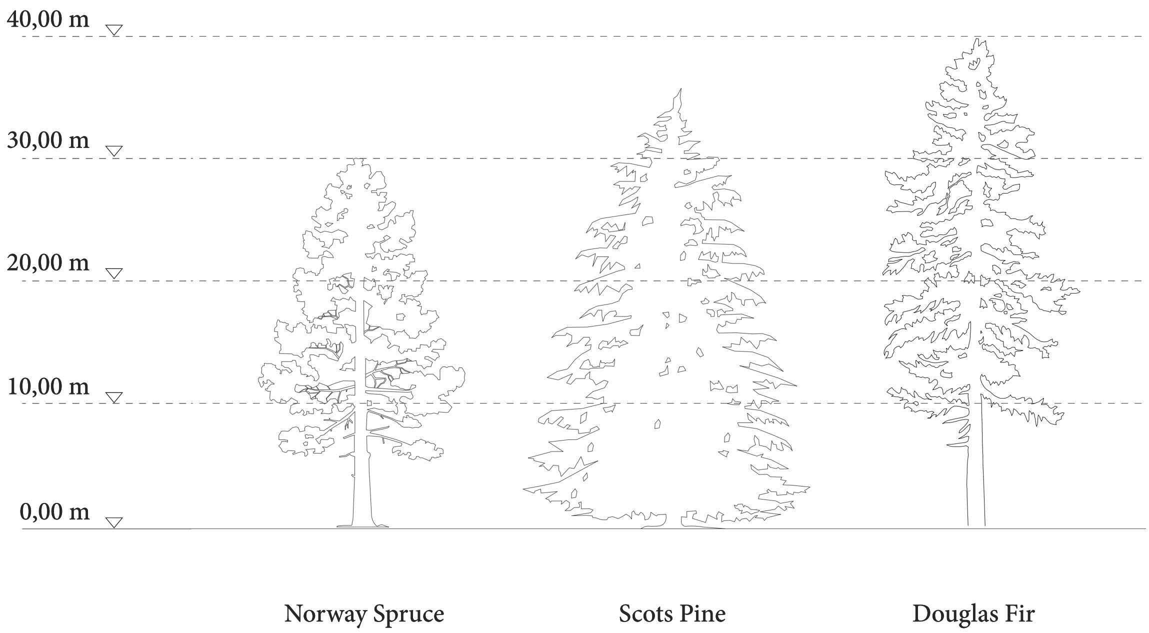




*fig. 14: The Ecologic Forest - tree species selection*

comprehend the complexities and interdependencies of the ecosystem. More specifically, knowledge must be produced beyond the performance of single instances that captures the holistic benefits of forests. Especially in times of climate emergency and unpredictable climatic transformations, resilience against disturbances gains importance and must be higher valued than the performance of single components.

### *3.3. The Hybridized City Forest*

#### *3.3.1 Description and Overview of Scenarios*

In 2050, more than 70 percent of the world´s population are expected to live in cities (Konijnendijk, 2018). This development of rapid urbanization results in a loss of natural ecosystems and a depletion of habitats (Salbitano et al., 2016). That is why the expansion of cities necessitates a sustainable approach to ensure biodiversity and climate adaption. One way of approaching this dilemma is the implementation of forests into the urban mesh. The Hybridized City Forest departs from the potentialities of blending ecological diversity with the cityscape. It seeks to reveal the various benefits of combining tree growth with urban life. Therefore, it poses the question of how to translate the previous typologies (carbon sink, ecologic forest, and economic forest) into the urban context. Based on the 30-year time frame of the scenarios, it becomes critical to introduce environmental dynamics into the urban flux. The ambition is to allow "for both, ecological succession and human occupation" in a process-oriented design approach (Reed and Lister, 2020). Contextualized in the prospective development of Almere Pampus, the following design experiment is situated in the south-west of Pampus adjoining to the Ijsselmeer. The current land use of the northern part of the plot serves agricultural purposes while the southern part is occupied with trees (see fig. 15).

**2033** In 2033, the typology of the Hybridized Urban Forest has been divided into three different typologies, namely The City as Carbon Sink, The Economic Forest and The Ecologic Forest (see fig. 16). These types are divided along a diagonal urban axis that constitutes the central element of the design. The zoning of the different scenarios has been predetermined by the existing land use. Designed with the premise to allow a high degree of adaption and highlighting environmental and urban dynamics, each of the different scenarios consists of two elements - stripes and fills. The stripes build the main structure of the scenarios and act as permanent elements. They are designed to create synergies between urban functions and ecological systems. The fills perform dynamically and expand or shrink according to the future development of Almere Pampus. In 2033, the structure of the different stripes and fills is set up and the construction of Almere Pampus has begun. It renders a state in which the area has a high ecologic value with a rural density of housing.

**2053** In 2053, Almere Pampus is planned to be fully erected to provide housing for around 50.000 people (Gemeente Almere, 2021). Therefore, this scenario portrays a state of maximal urban expansion that still provides the benefits of the different forest typologies. The urban growth results in an entanglement in which the typologies of Ecologic Forest, Economic Forest and Carbon Sink successively grow into each other (see fig. 17). The layout and structure of the site allows to accommodate dynamic urban process and fosters the creation of synergies between natural ecosystems and urban life. This process reflects a non-binary approach to urbanism that dismantles the dualism between city and nature.

Next, each typology shall be further detailed in schemes that show their development from 2023 to 2033 and 2053. These schemes shall outline seminal factors in the implementation of hybrid forests and depict the potential of synergies.

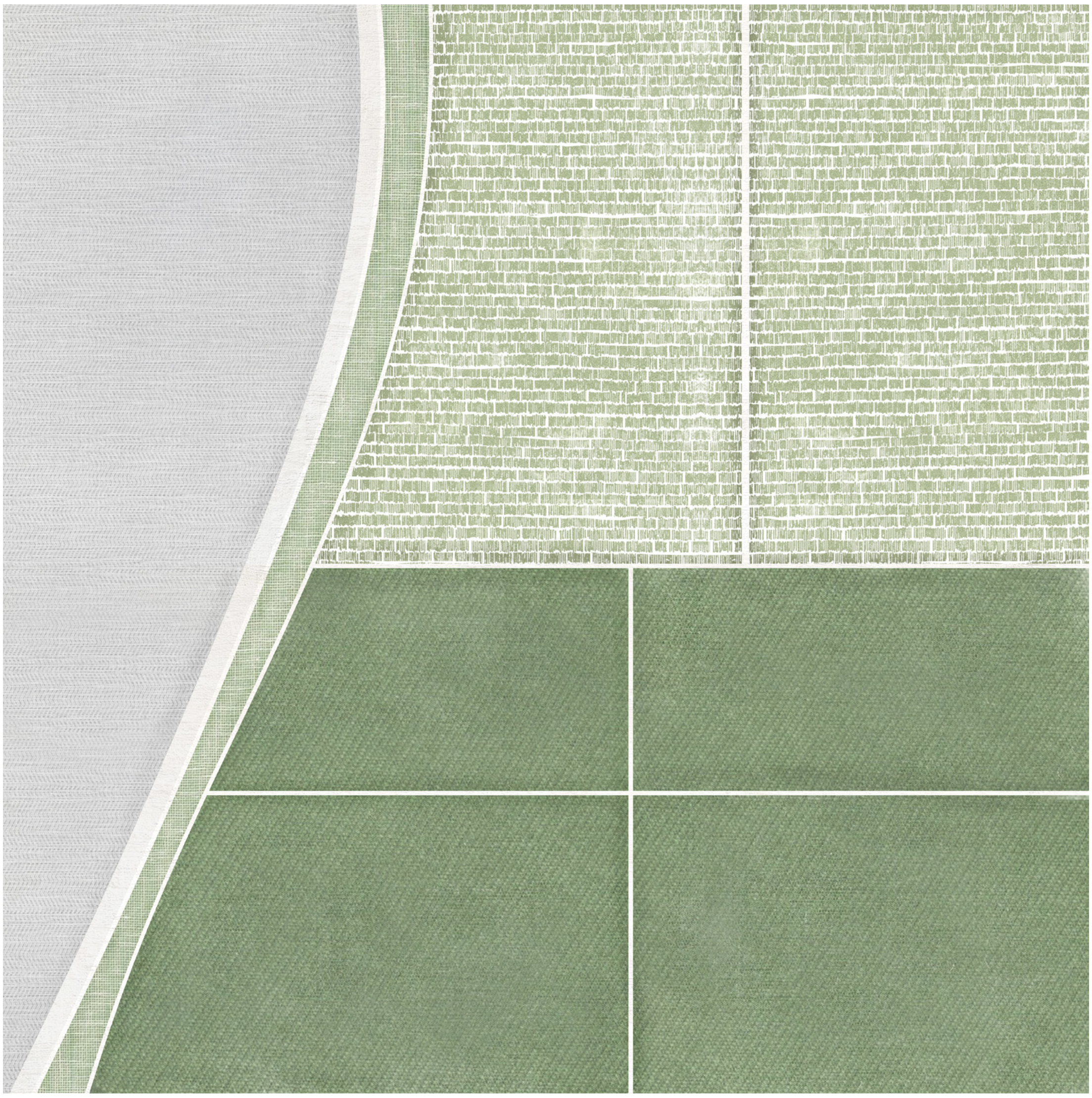


*fig. 15: The Hybridized City Forest, 2023*

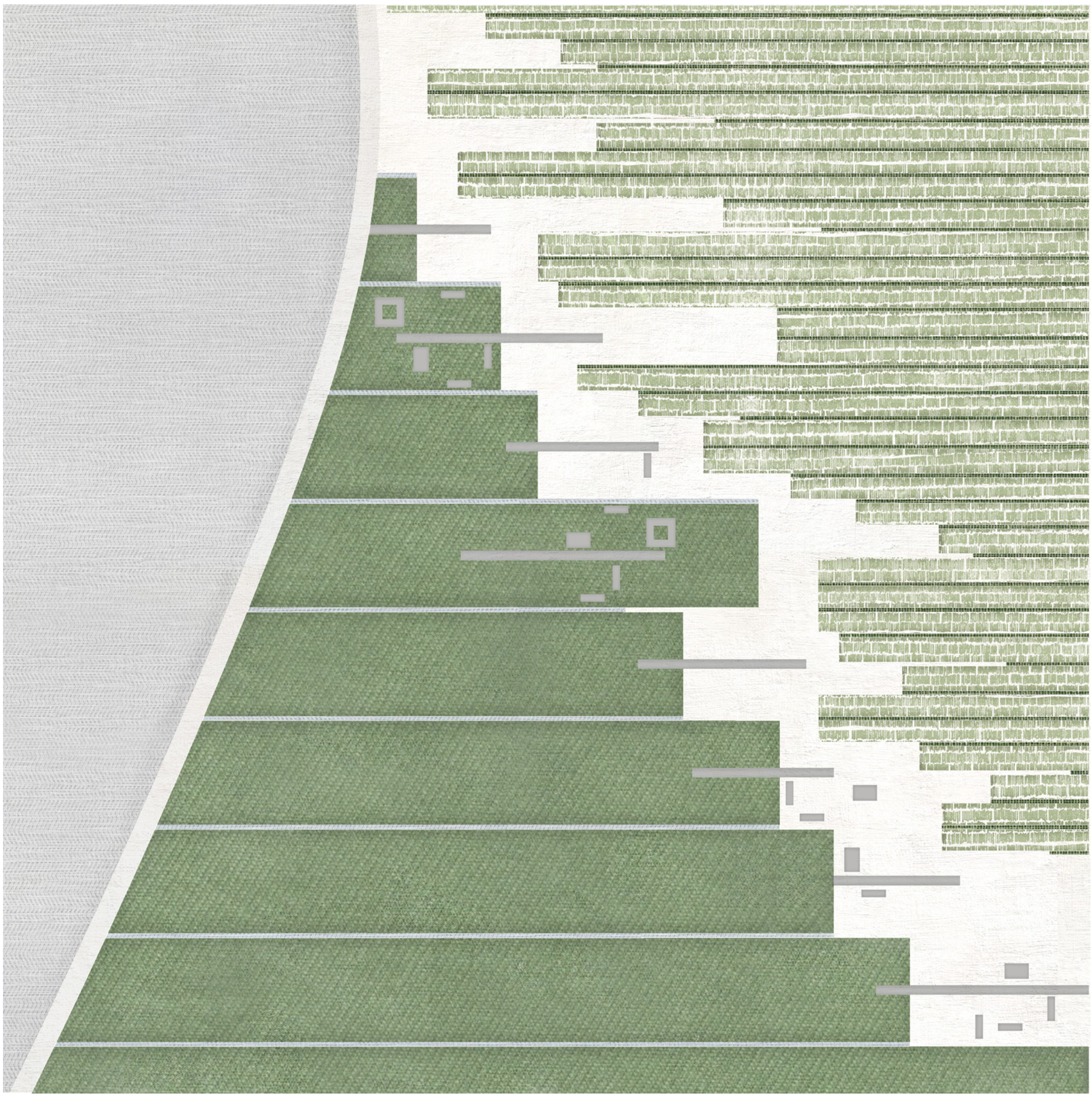
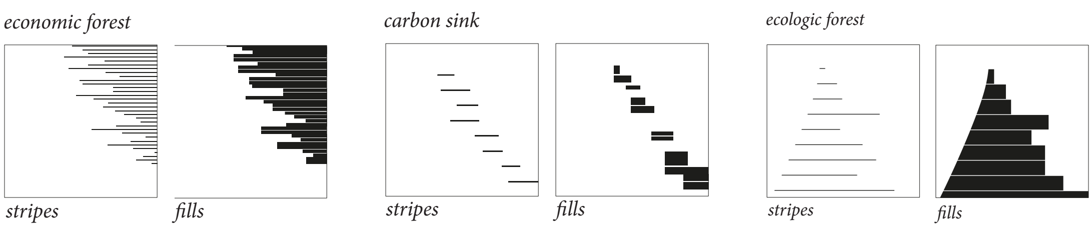


fig. 16: The Hybridized City Forest, 2033



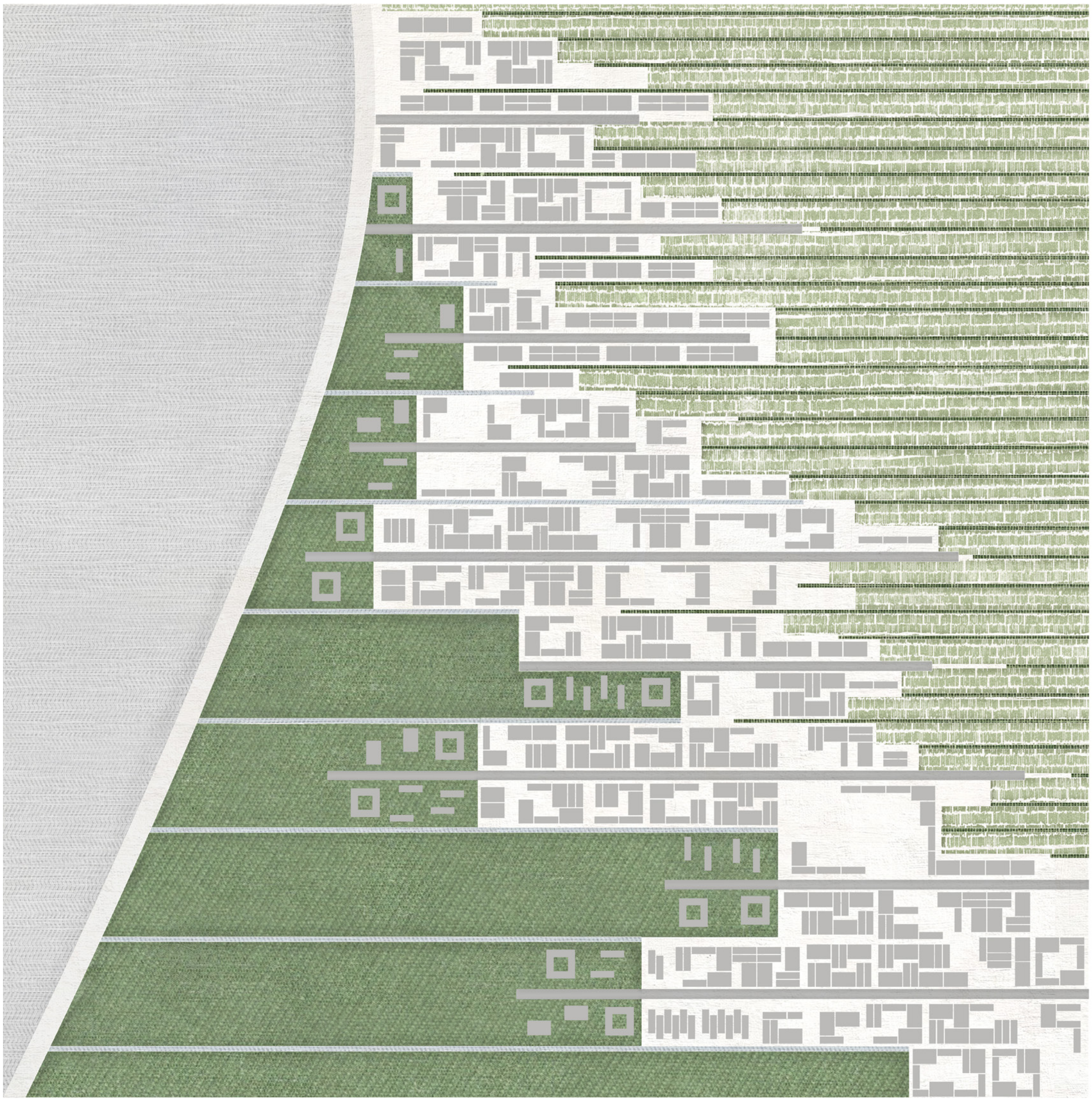
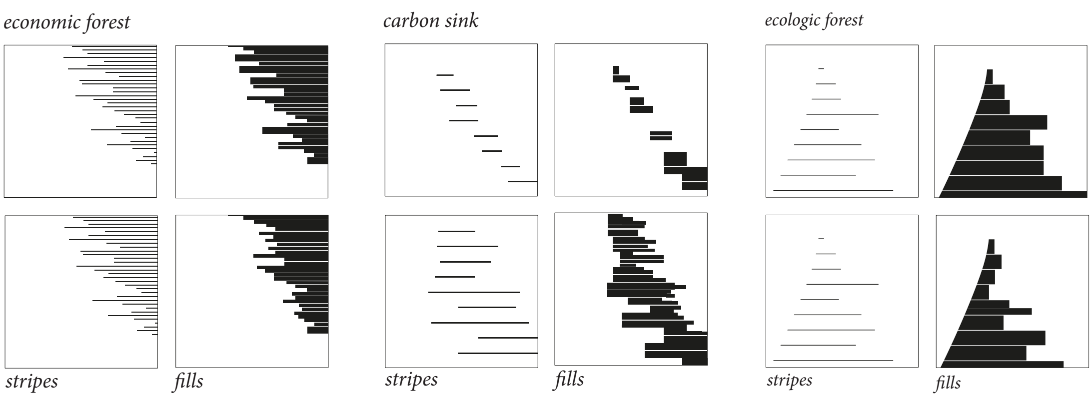


*fig. 17: The Hybridized City Forest, 2053*



### *3.3.2 City as Carbon Sink*

With the recent upheaval of timber as construction material, the possibility emerged to face increasing urbanization, a potential thread to the global climate, with timber´s intrinsic carbon storage capacity (Churkina et al., 2020). The typology "City as Carbon Sink" explores the potential of transforming cities from sources of C02 into carbon sinks. Research lays out that a five-story residential building constructed in laminated timber stores more C02 on a square meter than the aboveground biomass of a natural forest with the highest carbon storage capacity (Churkina et al., 2020).

**2033** In the frame of the development of Almere Pampus, the typology City as Carbon Sink suggests a transformation from the existing land use of agricultural production and forest area into an urban district. The site is characterized by the introduction of the elements of stripes that are translated into streets and fills that get consecutively transformed into buildings (see fig. 19).
First, the required density has been calculated by determining the number of inhabitants per hectare in consideration of the Almere Pampus development goals to house approximately 50.000 people (Gemeente Almere, 2021). For matters of simplification, three different building types have been chosen to accommodate the required number of 8900 people and to assess the carbon storage capacity of the timber construction. Here, the investigation draws on an existing study that emanated the Timber City project and calculated the amount of stored carbon in each building type (see fig. 18) (Organschi et al., 2016).

**2053** The scheme of 2053 depicts the site in a fully developed state. To construct an effective carbon sink that provides net benefits in substitution with forest area, it requires certain density that goes beyond single family housing (Organschi et al., 2016). Therefore, the mid-rise buildings accumulate to a city density of 0,4

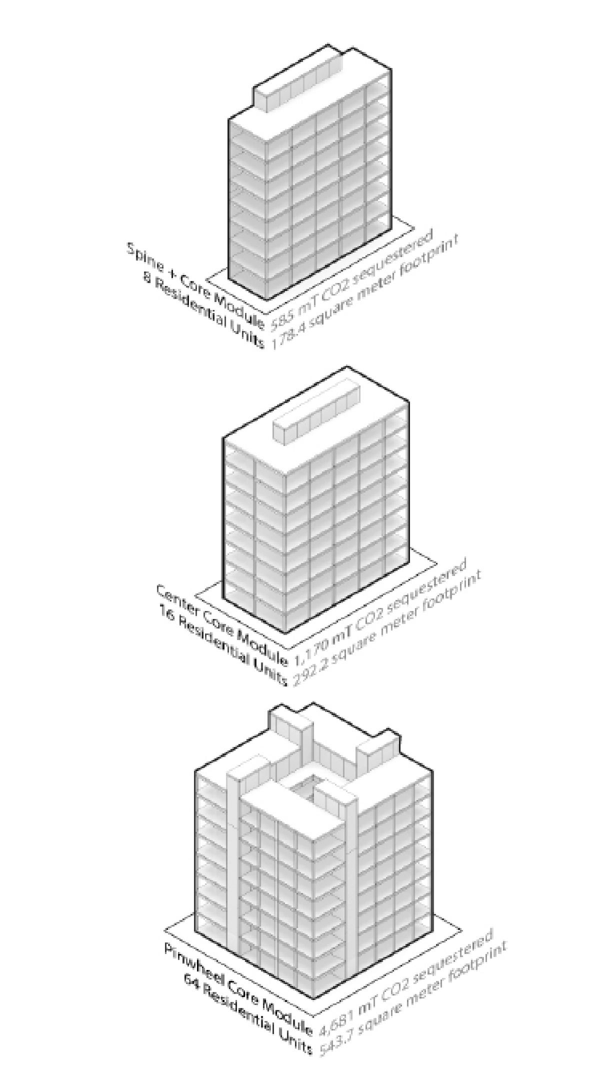
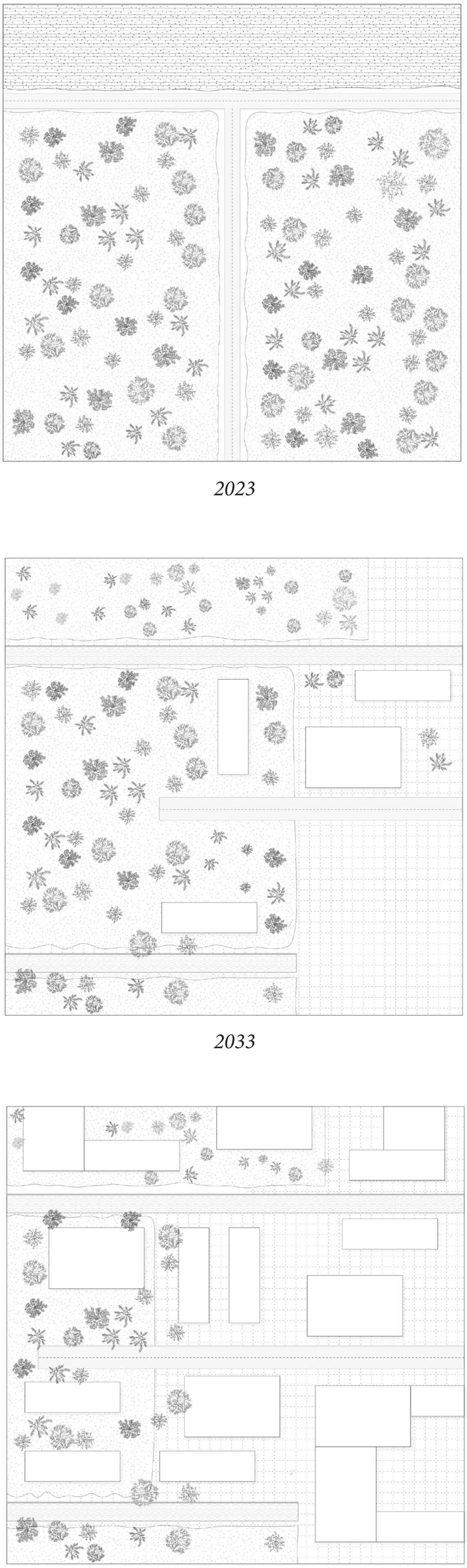



*fig. 18: Building typologies with amount of sequestered*

built area per plot.
Through the expansion of the city along the previously implemented horizontal structure of streets, the typology of the City as Carbon Sink blends with the adjacent typologies of the Economic and Ecologic Forest. In these moments of encounter, synergies are created with the stripes of the other two typologies. Rows of productive trees perforate the urban realm and introduce the advantages of greening such as social benefits and the improvement of the microclimate (Campbell, 1999). The stripes of the Ecologic Forest are horizontally oriented canals connecting to the Ijsselmeer. In the urban context, it functions as a drainage system that reduces water stress on the sealed area.



*2023*

*2033*

*fig. 19: City as Carbon Sink - schemes*

*2053*

Large-scale timber construction offers a potential solution for the wicked problem of providing an increasing amount of housing while reducing C02 emissions. The previous analysis outlines insights in the construction of carbon sinks such as a required density to substitute forest area with urban space with a net benefit of sequestered carbon. Another important aspect of urban carbon sinks is the life span of timber buildings. Churkina et al. (2020) suggest a more durable construction that leads to long-term carbon lock. A lifespan of 100 years would offset the released carbon in the building material by 3 times, considering an average rotation cycle of 30 years.

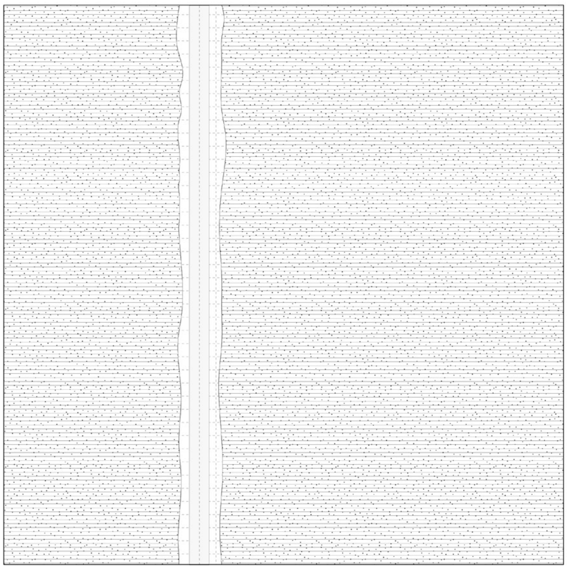
### *3.3.3 The Economic Forest*

In the urban context, the Economic Forest focuses on hybridizing ecologic, economic and social benefits. Agroforestry, as one distinct type of productive greening, inheres the potential of combining all these factors. It has been defined by different authors as "the deliberate integration of trees with agricultural crops and/or livestock either simultaneously or sequentially on the same unit of land" (Rigueiro-Rodriguez et al., 2009). Reasons for the recent upsurge of agroforestry systems are increasing soil erosion and decreasing biodiversity. This typology seeks to tackle these issues by purposefully combining wood perennials and agricultural crops in an interacting layout.

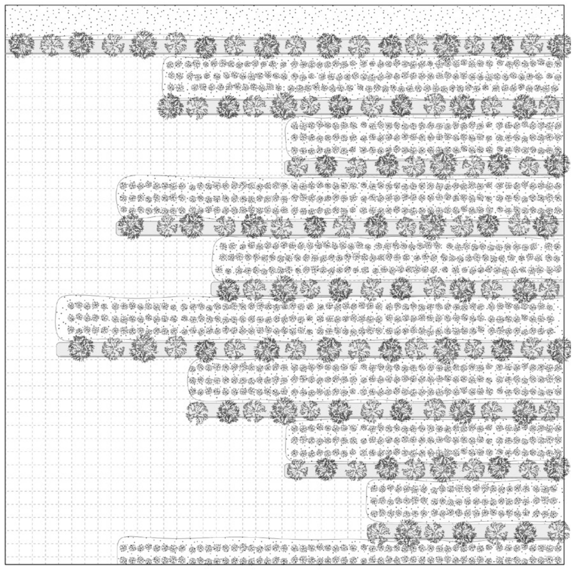
**2033** Until 2033, the existing agricultural land use shall be transformed into a system of agroforestry called alley cropping. Here, trees and shrubs are planted in rows creating alleys in which agricultural crops are produced (see fig. 20) (MacFarland, 2017). This layout resonates with the concept of stripes (permanent) and fills (adaptable), explained earlier to ensure the synthesis of agricultural production and urban benefits. In optimal conditions, trees increase the total yield by creating a more temperate climate and reducing wind speed (Luske et al., 2020). Among the myriad possible combinations, walnut and wheat have proven to interact synergistically. The walnut tree carries its leaves for a relatively short period between late spring and early autumn allowing extended crop growth (Luske et al., 2020).

**2053** The scheme of 2053 depicts the removal of every second row of trees, witnessing the increasing shading from mature trees. As trees create different microclimates throughout their lifespan and considering the objective of preventing soil exhaustion, research suggests rotating crops such as different kinds of grains (Luske et al., 2020).
The stripes consisting of walnut and poplar trees stay in place and perforate the city. The novel urban context profits form the diverse advantages of tree growth such as its capacity to improve human health and well-being (Salbitano et al., 2016). The economic factor of agricultural production is introduced into the urban realm while profiting from the social benefits of trees. This exemplifies a transition from the commodification of trees and monocultures to an approach that acknowledges the advantages of trees and plants holistically.

The Economic Forest lays out an adaptive strategy for the site under investigation that shall undergo the transition from current agricultural land use to the developed state of Almere Pampus within 30 years. The implementation of a system of agroforestry creates the potential of synergistically combining productive plantations with the diversification of ecosystems and the various urban benefits of greening. Furthermore, the fast rotation cycle of crops allows the flexibility of adjusting to the process of urban development accentuating its suitability for plots with changing land use.



*2023*



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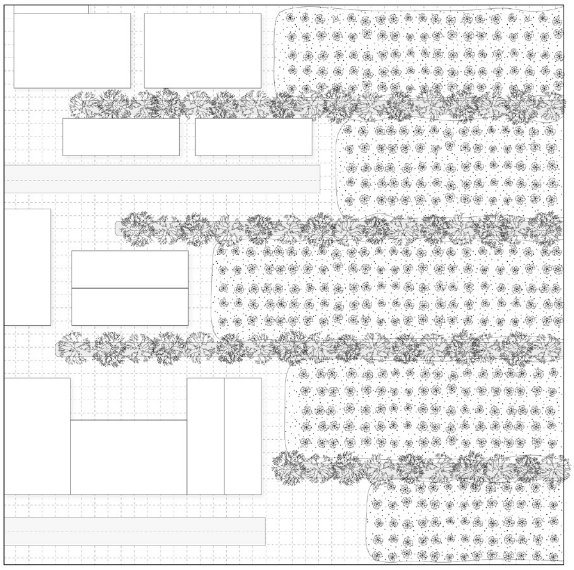


*fig. 20: The Economic Forest - schemes*

*2053*

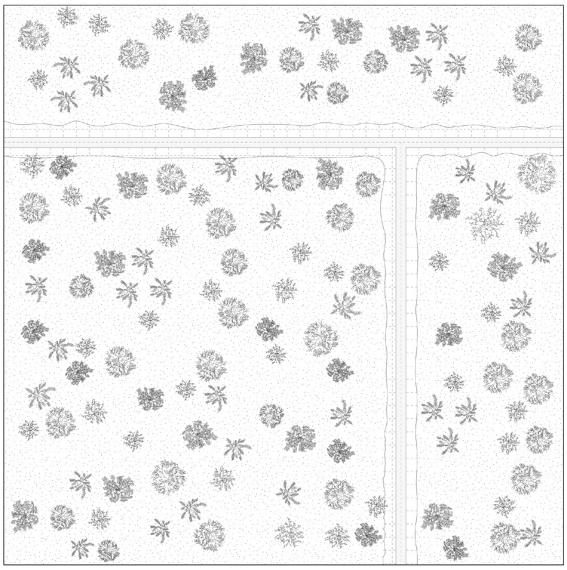
### *3.3.4 The Ecologic Forest*

Literature points out that urban forests experience an increased interest. A major reason for this development is that they offer a refuge from growing stress that is related to life in the city (Konijnendijk, 2018). Natural forests entail a certain degree of wilderness and provide a "psychic distance" from urban psychological stress (Konijnendijk et al., 2005). Contrasting the urban realm with an absence of clear geometries and formalities, woodlands appear to suit this very objective by actively improving human well-being (Konijnendijk et al., 2005). Besides the positive effects on human health, woodlands here conceptualized as the Ecologic Forest provide space for a great variety of different ecosystems and natural habitats (Konijnendijk, 2018). The following schemes of this typology focus on accentuating the social and environmental importance of forests by combining urban activities with an ecologically rich environment.

**2033** The typology of the Ecologic Forest is composed of stripes (water canals) and fills (forest area) structuring the site. Until 2033, the existing forest shall be made accessible by offering a variety of leisure opportunities that increase its attractivity (see fig. 22). Providing the possibility for diverse activities such as sport, playing and gathering offer "a place for everyone, including otherwise marginalized groups" (Konijnendijk, 2018). Here the urban forest manifests its importance as a public space that is not controlled by any social group. Elements such as paths, planting patterns and open spaces are designed to evoke the impression of naturalness to contrast the clear geometry of the forest layout and the deterministic urban realm.

**2053** The scheme of 2053 depicts the typology of the Ecologic Forest in the context of Almere Pampus in a fully developed state. The city blends with the forest profiting from trees that now punctuate the urban fabric. The layout of the mixed forest was designed in consideration of prospective urban processes that allow an integration of the functions into the city. Hence, the leisure opportunities are placed at the edge of the forest constituting an east-west gradient from a function based to a more natural layout. The water canals that separate the forest patches provide habitats for diverse species. Perforating the city, they create a synergy operating as a drainage system and thus supporting the water infrastructure of the district.

The Ecologic Forest renders how the process of urban development can be used to prepare the site with the ambition to offer an added value to the future city life. Today, natural outdoor areas play a fundamental role for the attractivity of cities (Konijnendijk, 2018). This typology is designed to counteract the psychological stress induced by city life while creating a diverse ecosystem.



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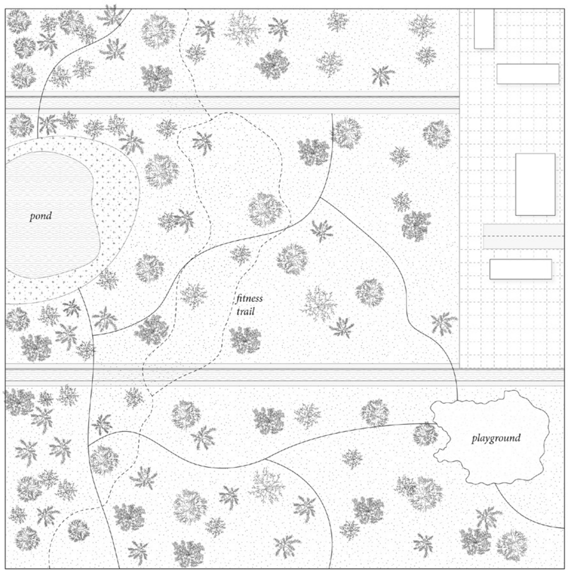


*2033*

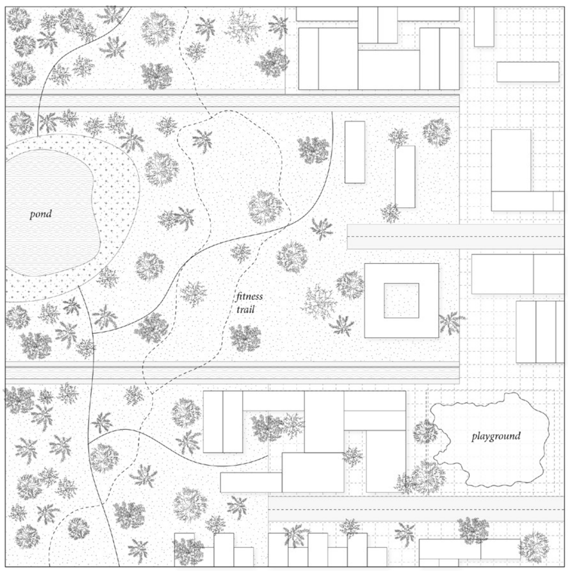


*fig. 21: The Ecolomic Forest - schemes*
*2053*

## *Part IV: Discussion*

### *4.1 Discussion*

The building sector consumes finite resources that have a massive impact on global warming and induce anthropogenic landscape transformations (Organschi et al., 2016). In the context of rapid urbanization, this paper explores the potential of turning the built environment into an effective carbon sink that entails a reduction of embodied carbon dioxide emissions. Therefore, synergies between the forest and the city have been outlined to move from a commodification of timber to a strategy that embraces the holistic benefits of trees. The research works with a case study to link it to specific territorial conditions, yet it has encountered limitations in contextualizing the project into conditions that go beyond ecological and environmental factors, such as ownership and maintenance models.
Fundamental in the reduction of embodied carbon dioxide emissions is the localization of the different processes of the CLT supply chain. Localizing timber production offers the potential to benefit from the intrinsic ecological, environmental, and social benefits of trees. In this research the timeframe of the development of Almere Pampus has been juxtaposed with the process of tree growth. As a result of this iterative research and design exploration that investigated the spatialization of hybridizing urban life and timber production, a framework can be proposed that accounts for the embodied carbon dioxide emitted during the construction of a city development project. It responds to the question, how much of a carbon sink a city can become if one commences considering the emissions during resource extraction, transport, and disposal. Point of departure of this framework is the neglect of embodied carbon emissions and the outcome of the analysis that the rotational cycle of spruce (45 years) to produce CLT exceeds the time frame of the urban development from planning to execution. Hence, trees that are locally planted at the beginning of the planning process cannot be used in the construction of the district.
Important to emphasize here is that the following framework is based on the time horizon of the specific urban development project that is under investigation. Further research could analyze if the framework is adaptable to projects at different scales with different time frames.
The framework operates in three steps in relation to the timeframes of the project (2023, 2033, 2053). It starts by planting the amount of trees that are estimated to be used in the construction of the project. In the first timeframe from 2023 to 2033, the construction timber shall be imported from abroad. Here, the effectiveness of the carbon sink is reduced by 32 percent (Orr et al., 2020). This stems from the deduction of the embodied emissions from the sequestered carbon captured in construction timber. In the second step from 2033 until 2053, a CLT factory has been erected. Thus, timber from existing coniferous forests in the Netherlands can be used for the buildings constructed in this timeframe. This reduces transport and subsequently the embodied emissions of timber. From 2053 on, the initially planted coniferous trees can be logged and utilized locally in other constructions. The primal emissions from transport have been offset and accounted for. This reduces the embodied C02 emissions by 25 percent in comparison with imported timber (Orr et al., 2020).
This framework suggests an approach in which developments do not only have to account for operational, but also embodied emissions of buildings. This could be the point of departure to investigate the implementation of a policy that addresses, regulates, and maximizes the potential of turning urban areas into effective carbon sinks. Future research could be directed to further analyze the synthesis of timber production with urban planning strategies from a perspective of policies.

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