# THE REED CYCLE

*How Constructed Wetlands and Biomaterial Architecture Close the Nitrogen Loop*

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The Netherlands carries the highest nitrogen deposition per hectare in Europe, and its nutrient-poor ecosystems, heathlands, wetlands, and the stream valleys of Brabant, are least able to absorb it. This thesis proposes a public building in the valley of the Dommel that treats the nitrogen problem not as a constraint to avoid but as a process to build with. Architecture and landscape are designed as one system. A constructed wetland filters nitrogen from the river while restoring the nutrient-poor stream-valley ecology that historically existed there. The reed harvested from that wetland becomes the building's primary material, thatch, bundled structural arches, insulation, and a ventilated pressed-fibre façade, making the building both a product of the landscape and the place its material is processed. Developed across territorial, architectural, and material scales, and tested through mapping, precedent study, and physical prototyping, this project demonstrates how a building can run on the ecological cycle it teaches.

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I'm a master's student in Architecture at the Delft University of Technology, graduating in the Architectural Engineering studio. This project reflects a way of working I enjoy most; moving between disciplines, testing things by hand, and trying to bring technology, material and building into one coherent design.

**Graduation studio - Architectural Engineering**

Architectural Engineering brings together architecture and technology in a societal context, encouraging students to face today's challenges from a systemic point of view. Sustainability themes, circularity, building culture, biodiversity, and climate adaptivity, are central to its search for renewal in architecture. Its work is organised around three research-by-design domains: Stock, Make, and Flow. The studio's guiding question reframes the usual order of things: if technology is the answer, what is the design question? This project sits most directly in Flow, a building organised around the movement of water, nitrogen, and material, while drawing on Make in its hands-on material research.

***What & Why***

*This chapter frames the nitrogen crisis as more than an environmental problem as a spatial and architectural one. It sets out why a question usually left to policy deserves a designer's attention, and defines the objectives, scope, and guiding questions behind the project.*

1

# Introduction

Nitrogen as Spatial Condition

Nitrogen as disrupted metabolism

Architectural ambition: Redirecting the cycle

Research & Design Questions

# Nitrogen as spatial condition

Since the post-war decades, the Netherlands has built one of the most productive agricultural economies in the world. Intensification, mechanisation and spatial optimisation made food production extraordinarily efficient, and structurally dependent on high nutrient inputs and concentrated livestock. One consequence is that the country now records the highest reactive-nitrogen emissions per hectare in Europe (CBS, 2026).

In the Dutch case this is overwhelmingly an ammonia problem, released from livestock manure during storage and spreading; agriculture accounts for the largest part national nitrogen emissions (CBS, 2026). What makes ammonia a spatial problem rather than a farming one is geography. In a small, densely farmed country, emitted ammonia does not stay where it is produced: it travels through the air and is redeposited elsewhere, far from its source.

This redistribution is the heart of the matter. Nutrient-poor ecosystems, heathlands, wetlands, the stream valleys of Brabant, are precisely the systems least able to absorb it, and they collect a burden generated kilometres away. The map opposite shows the trap: in the Netherlands, intensive farmland and protected nature sit directly against one another, so emission and deposition are never far apart.

The 2019 annulment of the Programmatic Approach to Nitrogen (PAS) made this condition legally visible. The Council of State ruled the permit system incompatible with EU habitat law, and thousands of construction and infrastructure projects were suspended overnight (Raad van State, 2019). Nitrogen stopped being only an ecological concern and became a spatial bottleneck, a constraint on where and whether anything can be built. Despite reduction efforts, deposition remains structurally high. In other words, Nitrogen is not merely a regulatory problem, it's a material flow that reorganises the landscape across scales, and that is the condition this project takes as its starting point.

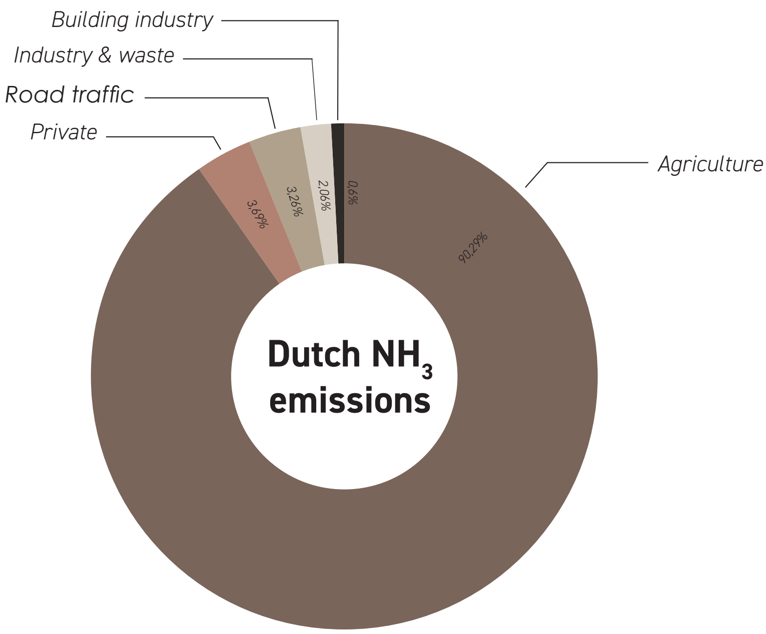
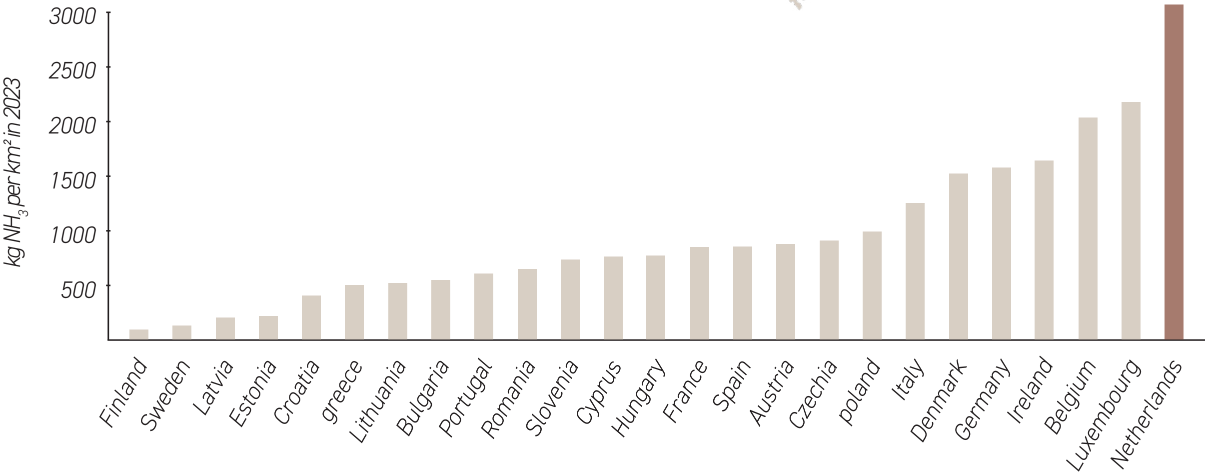


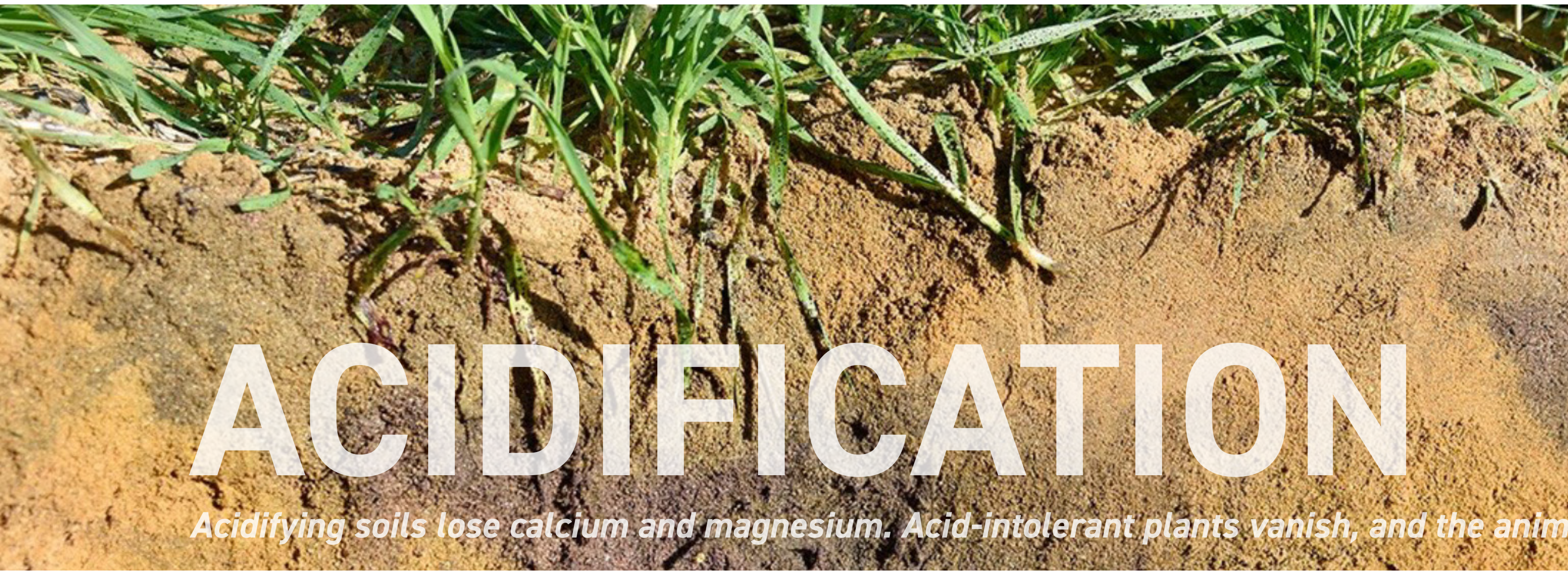

*Fig. 1: $NH_3$ Emissions per industry (CBS, 2026)*
*Fig. 2: Distribution of protected nature and Agriculture (Qgis, 2026 )*
*Fig. 3: Nitrogen deposition per country (European Union emission inventory report 1990-2023, 2025)*


Protected nature
Agriculture


3000
2500
2000
1500
1000
500
kg $NH_3$ per km² in 2023
Finland
Sweden
Latvia
Estonia
Croatia
greece
Lithuania
Bulgaria
Portugal
Romania
Slovenia
Cyprus
Hungary
France
Spain
Austria
Czechia
poland
Italy
Denmark
Germany
Ireland
Belgium
Luxembourg
Netherlands


INVASION
In nitrogen excess, vigorous generalists overrun the vulnerable habitat and erase its


EUTROPHICATIO
Nitrogen feeds algal blooms; as they decay, oxygen drops, and aquatic plants and fish


ACIDIFICATION
Acidifying soils lose calcium and magnesium. Acid-intolerant plants vanish, and the



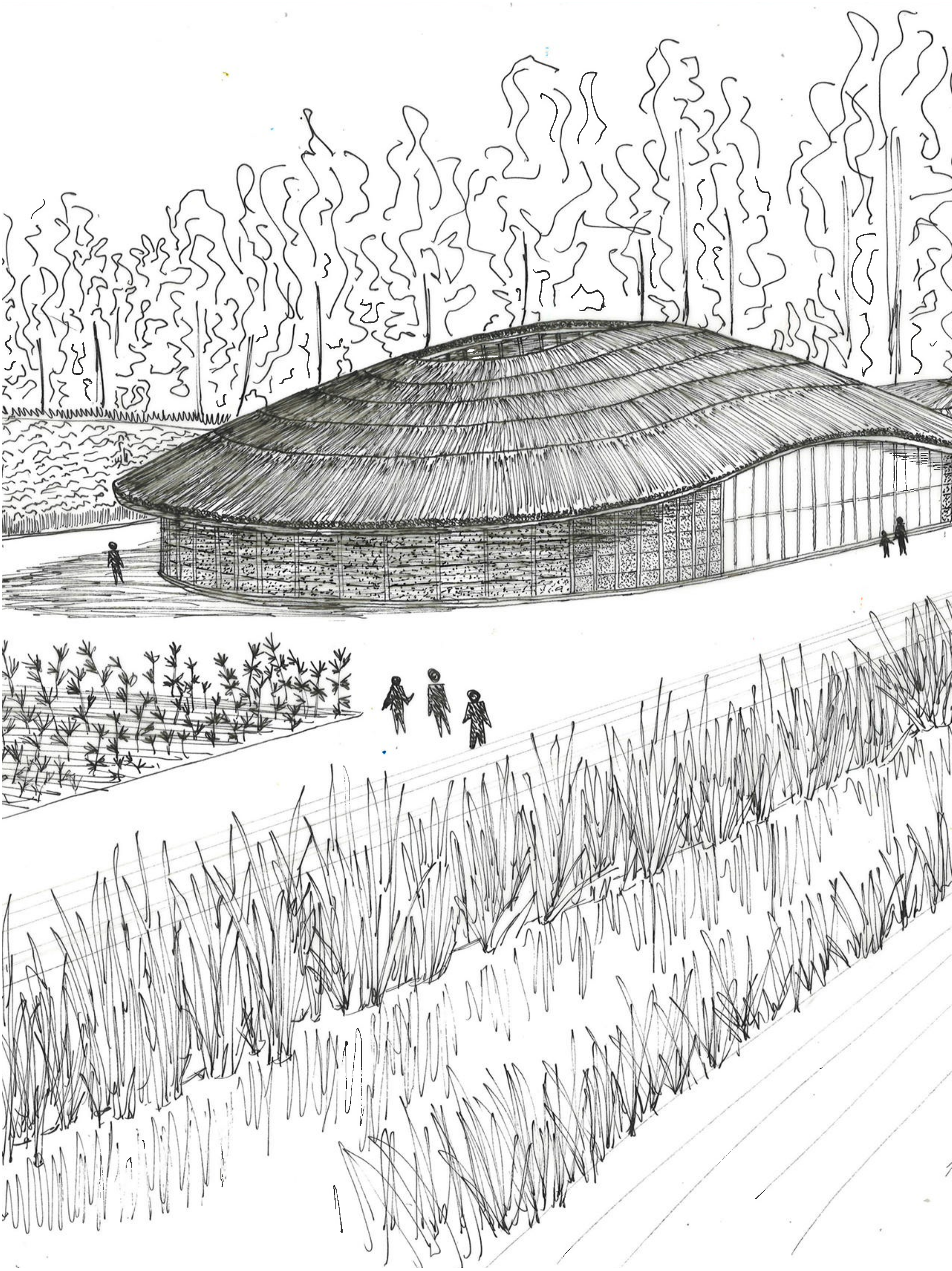
# A disrupted metabolism

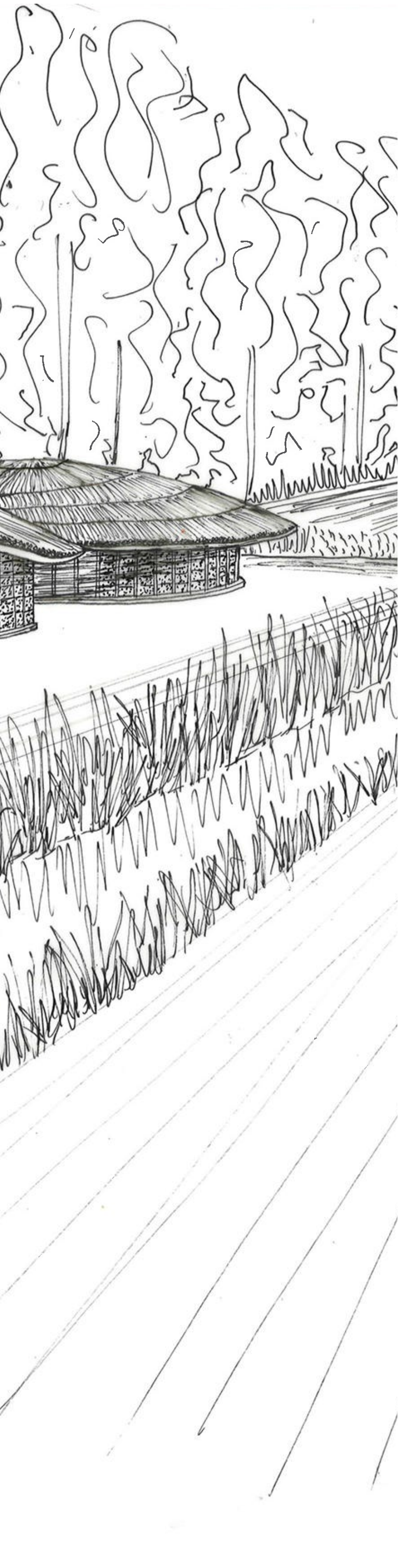
Nitrogen is not a pollutant by nature. It is a basic nutrient, cycling continually through soil, water, plants and air, and life depends on it. The problem is one of rate and balance: agricultural intensification has pushed reactive nitrogen into that cycle far faster than ecosystems can process it.

Once mobile, the excess accumulates where it does the most harm, in the nutrient-poor systems that evolved on scarcity. There it changes soil chemistry, drives explosive plant and algal growth, and squeezes out the specialists that defined these places. A cycle that once turned slowly has become concentrated and spatially misaligned.

The issue, then, is not nitrogen itself but the imbalance of its distribution, too much, in the wrong places, too fast. This is the metabolic disorder the rest of the thesis works on: not to remove nitrogen from the world, but to slow it, catch it, and put it back to use

*Fig. 4: Three Nitrogen effects on nature (helcom, 2026), (Gazey et al. 2019)*





# Architectural Ambitions

Nitrogen is almost always handled through regulation and emission targets. Architecture, when it engages at all, tends to respond passively, adapting to the constraint, treating it as a limit to work around rather than a process to work with.

This project takes the opposite position: architecture as an active participant in a landscape system. The building is not conceived as an object dropped into a site, but as one element in an environmental cycle that links water purification, material cultivation and public understanding. It does not sit beside the problem; it runs on it.

That cycle has a specific kind of place and a specific precedent. It belongs to the Brabant stream valleys of the Dommel, landscapes that, before drainage and fertiliser, were held low in nutrients by slow water and seasonal flooding. The project reaches back toward that lost ecology while putting its by-product to work: nitrogen drawn from the water grows reed, and reed becomes the building.

The ambition is therefore twofold. At the scale of the landscape, the intervention buffers water and nutrients and helps restore a nutrient-poor valley ecology. At the scale of the building, it makes that process legible, envelope, structure and interior all built from, and revealing, the material the landscape produces. The aim is not only to perform the cycle, but to let a visitor read it.

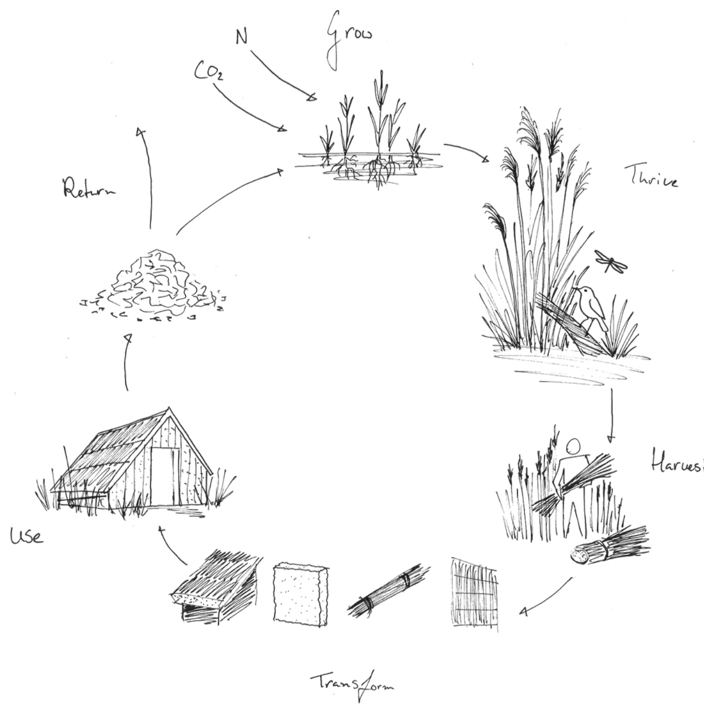



*Fig. 5: (B)old vision sketch*
*Fig. 6: Vision diagram*

# Research & Design Questions

The project is deliberately bounded. It does not attempt to resolve national nitrogen policy or to redesign a whole park or region. It develops one public building and its immediate landscape as a site-specific prototype, a single, legible instance of a cycle that could be repeated elsewhere along the river.

Within that scope, the work pursues one main research question:

*How can a public building and its landscape be designed as a system that filters nitrogen from the Dommel, restores the nutrient-poor stream-valley ecology, and is itself built from the material that process produces?*

This breaks into four lines of enquiry, each developed in a later chapter:

Landscape: *Which nitrogen-reduction strategies suit a low-gradient Brabant stream valley, and how do they combine into one constructed-wetland system?*

Material: *Can reed harvested from that wetland be processed into the building's structure, insulation, and façade, and with what performance and limits?*

Architecture: *How can structure, envelope and plan be organised so that the material cycle is not hidden but spatially experienced by the public?*

Time: *How does a building made of an annually harvested, biodegradable material handle replacement, seasonality and maintenance as part of its design rather than against it?*

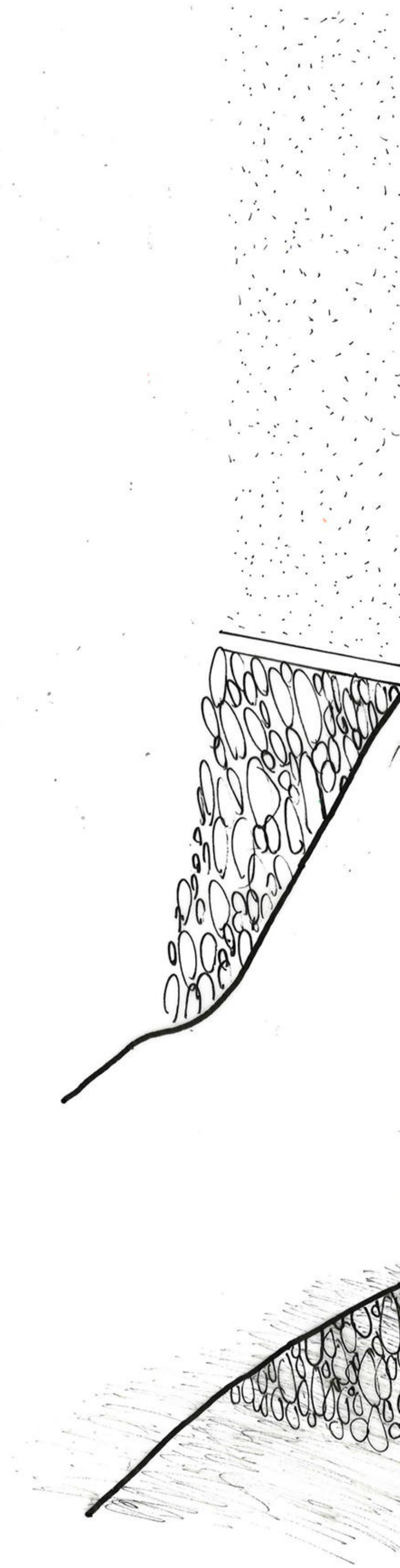
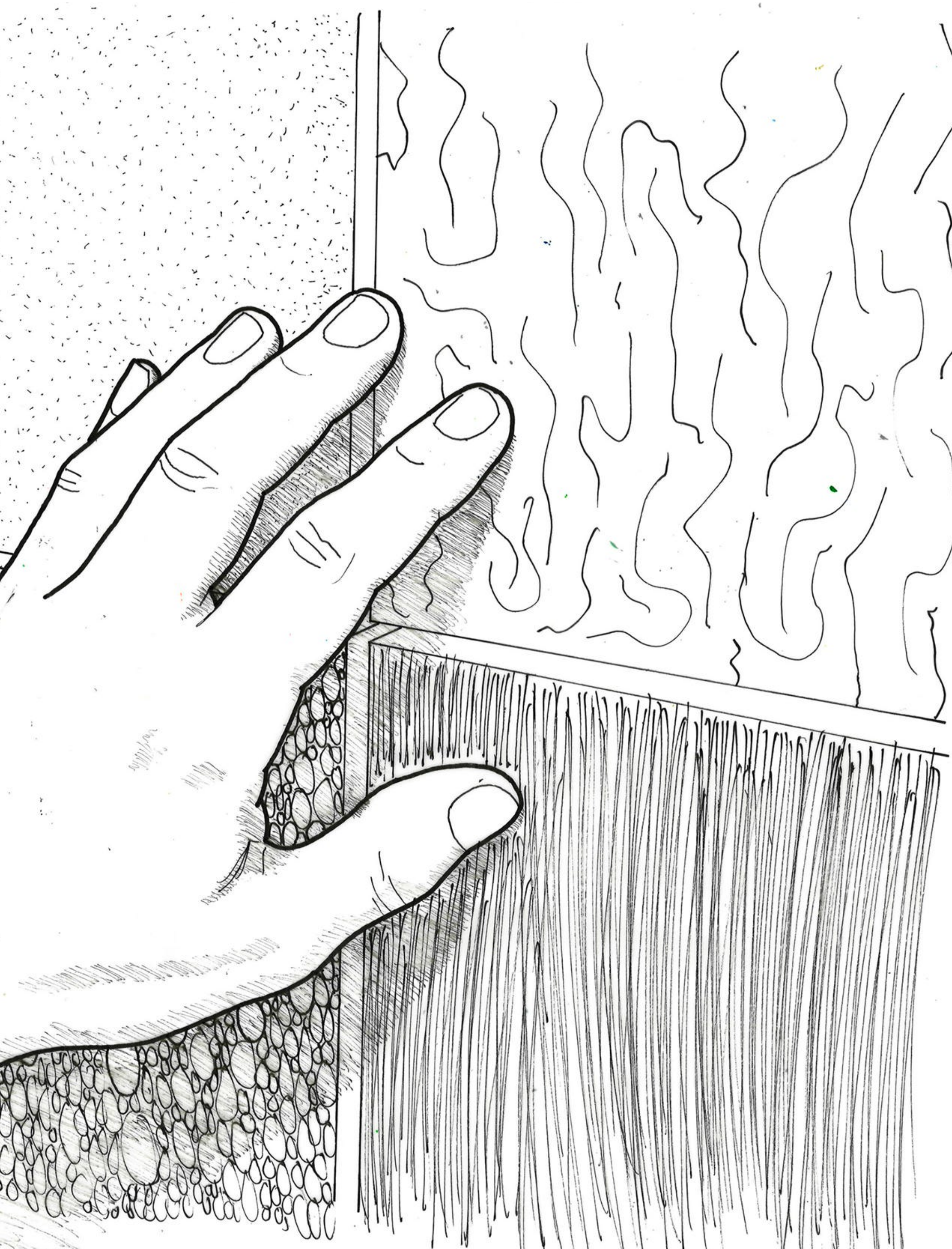
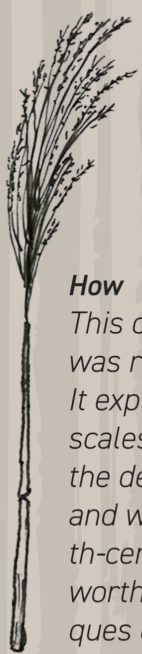


*Fig. 7: Interaction with embodied nitrogen*





***How***

*This chapter lays out how the project was researched and on what it stands. It explains the working method across scales, then builds the foundation the design rests on: what nitrogen is and where it lands, the lost nineteenth-century stream-valley landscape worth restoring, and the mix of techniques chosen to act on the problem.*

# Approach & Framework

Methodology

Nitrogen Interaction

Territorial Deposition

19th century stream valley landscapes

Evaluation of territorial reduction techniques

# Methodology

The research was structured by scale. Nitrogen, the wetland, and the building each operate at a different size, and each demand a different way of working. Three scales, territorial, architectural, and material, were investigated in parallel, so that landscape strategy, building design, and material development informed one another rather than running in sequence. At every scale I worked through the same cycle; defining parameters (what am I looking for), execution (drawing, reading, modelling), testing (did I find it, or back to parameters), and cross-scale feedback (what it means for the other scales).

<u>Territorial scale</u>: The relation between Eindhoven, the Dommel, and nitrogen flows was studied through mapping and the analysis of public datasets on emission, deposition, and critical loads, combined with site visits. The Province of North Brabant's ambition to return the Dommel toward its nineteenth-century valley landscape provided a policy and ecological framework. This was supplemented by informal consultation with a specialist in forestry and nature management, which grounded the floodplain and nitrogen-mitigation strategies in ecological practice rather than mapping alone.

<u>Architectural scale</u>: Design at the building scale proceeded largely through precedent study. Visitor centres, reed and thatch buildings, water-filtering architecture, and bio-based façade systems were analysed for their programmatic organisation, environmental integration, and construction logic. These cases informed both the brief for the centre and the way water management is brought into the building.

<u>Material scale</u> The material work was the most experimental and the most hands-on, pursued through physical iteration rather than literature alone. After establishing façade-performance requirements and reviewing existing bio-based constructions and the properties of reed fibre, the research moved into making: a cold-press mould was designed and built, and reed fibre was pressed with a range of bio-binders and fibre sizes, then evaluated for cohesion and façade suitability. Alongside the panels, the load-bearing reed connection was tested as a physical model, a ventilated reed façade was built as an exploded model, and façade-panel geometries were developed parametrically and 3D-printed for assessment. Designing by building, rather than only drawing, was the method itself at this scale.

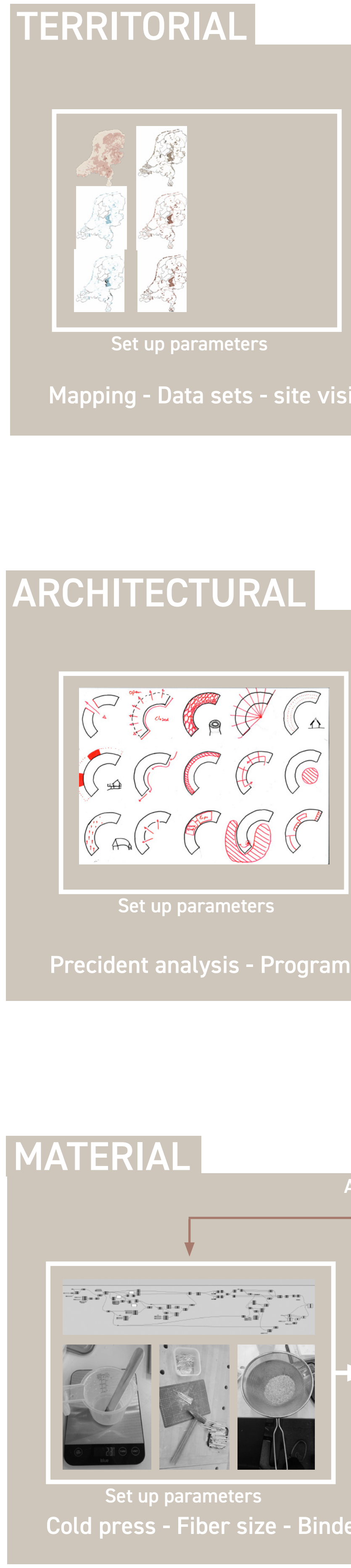
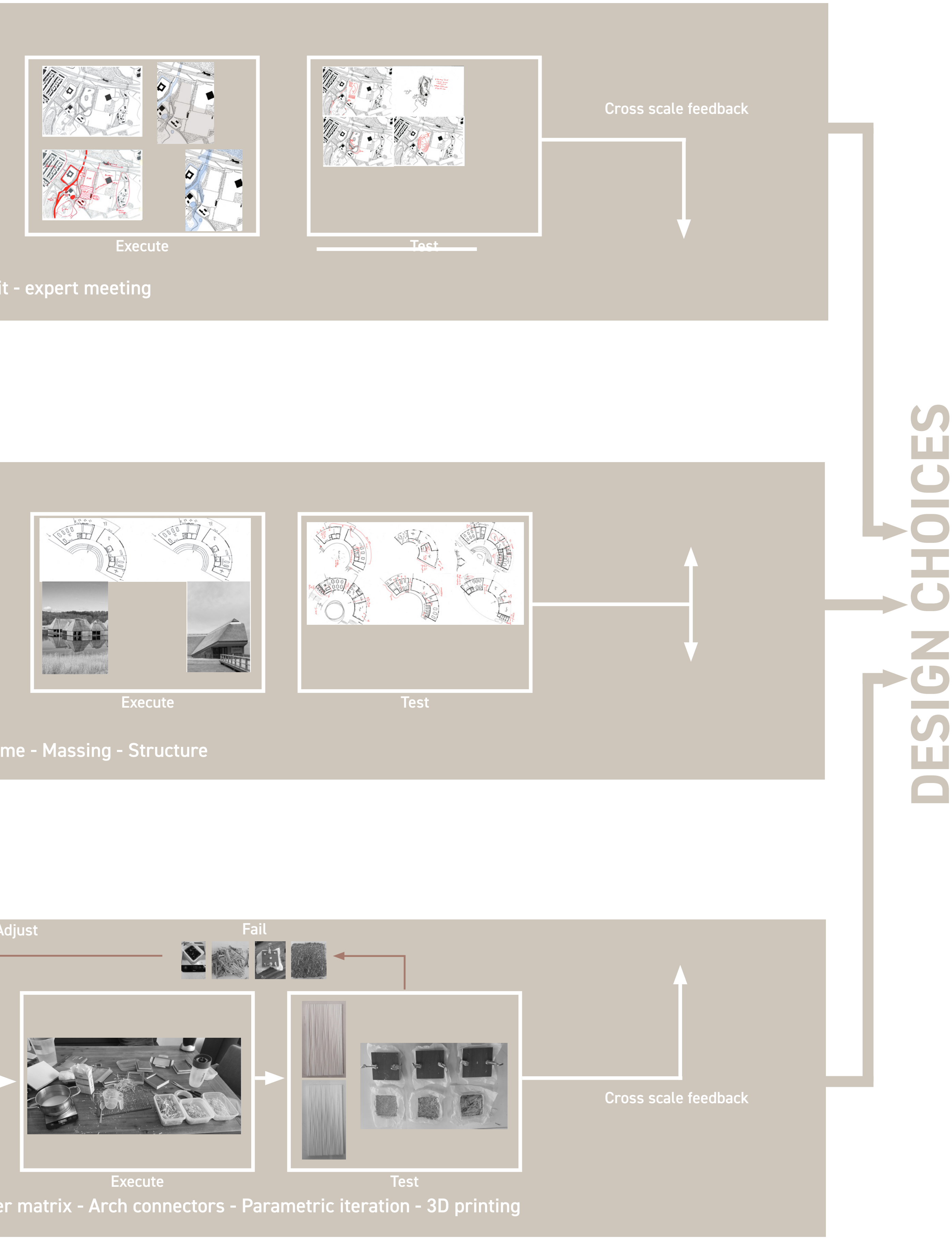



*Fig. 8: Methodology chart*
*(some example images added)*


Cross scale feedback
Execute
Test
it - expert meeting
Execute
Test
me - Massing - Structure
DESIGN CHOICES
Adjust
Fail
Cross scale feedback
Execute
Test
er matrix - Arch connectors - Parametric iteration - 3D printing

# Nitrogen Interaction

'Nitrogen' is shorthand for two very different problems. Nitrogen oxides ($NO_x$) come mostly from traffic and industry; ammonia ($NH_3$) and ammonium ($NH_4^+$) come mostly from livestock manure and fertiliser (Compendium voor de Leefomgeving (CLO), 2025). This project works on ammonia. It is the dominant deposition source near rural nature, and unlike traffic $NO_x$ it cannot be solved by cleaner engines, it has to be solved in the landscape.

Once airborne, ammonia settles downwind, caught more heavily by rough terrain like forest edges and reedbeds than by open ground (CLO, 2025). Where it lands on nutrient-poor systems, it acts as fertiliser: fast-growing species crowd out the specialists, and biodiversity collapses (OBN Natuurkennis, 2026, 5 februari). The damage scales with how little nitrogen a system evolved to tolerate, which is why the stream valley sits among the sensitive landscapes shown opposite.

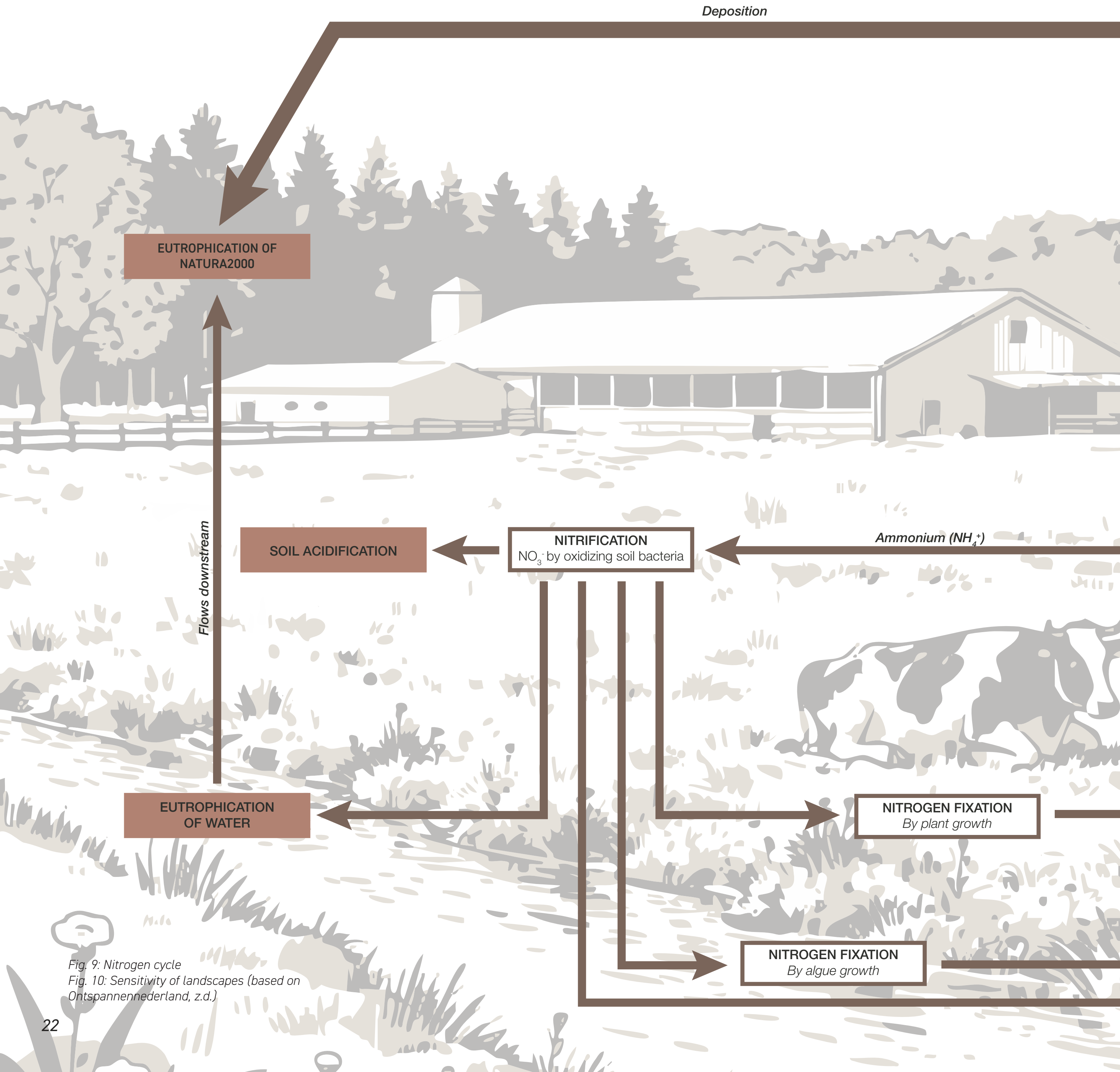
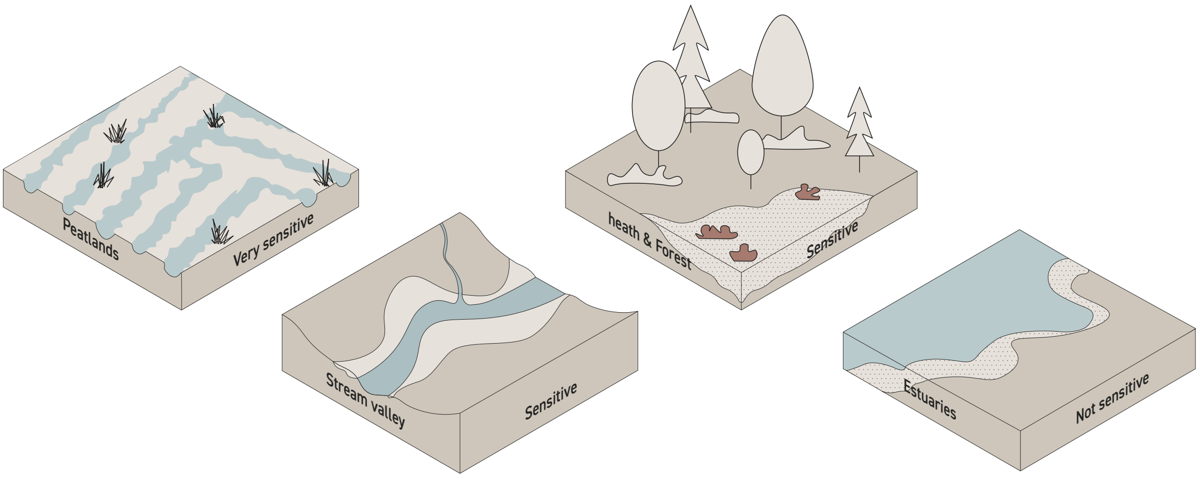
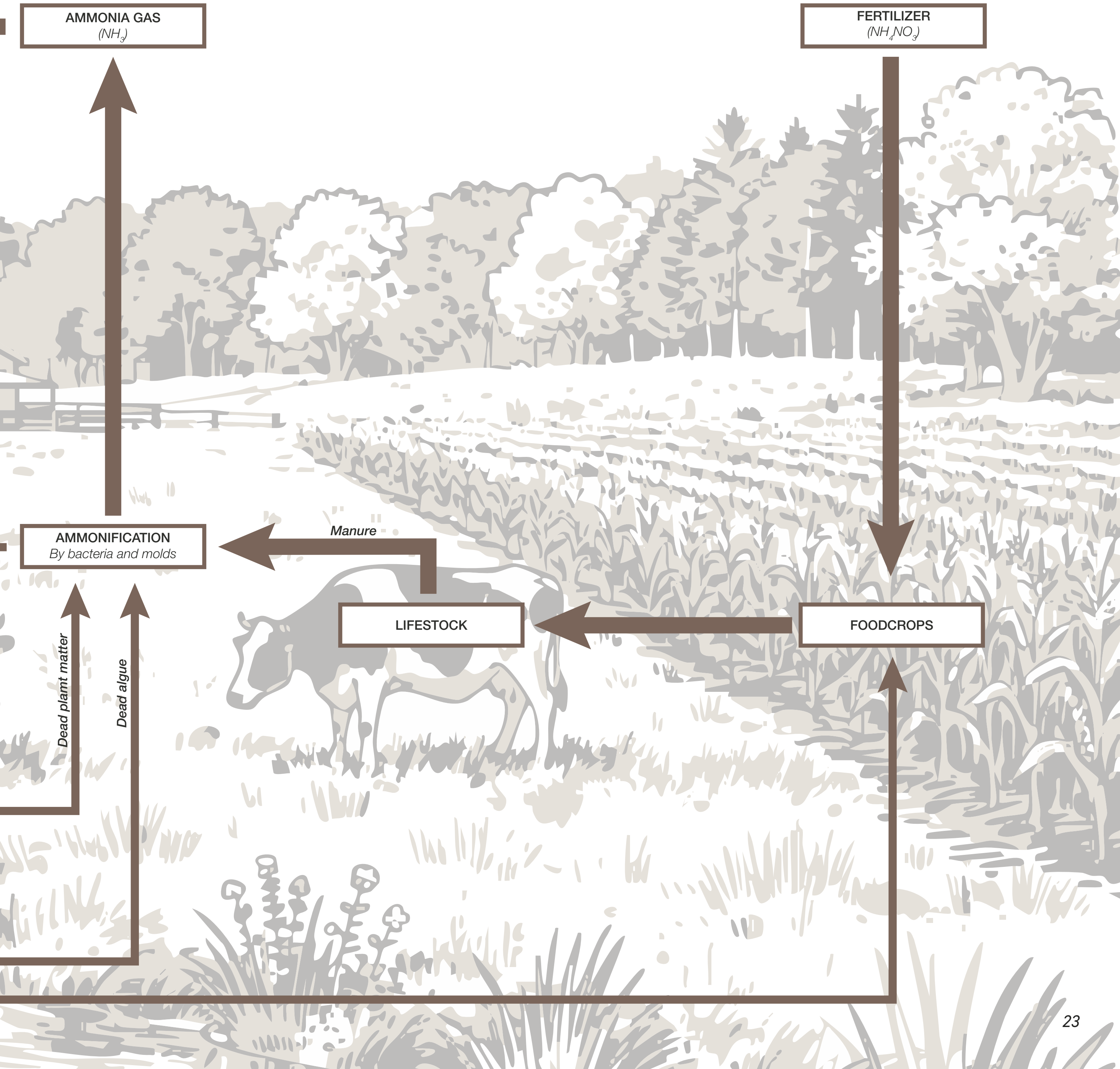
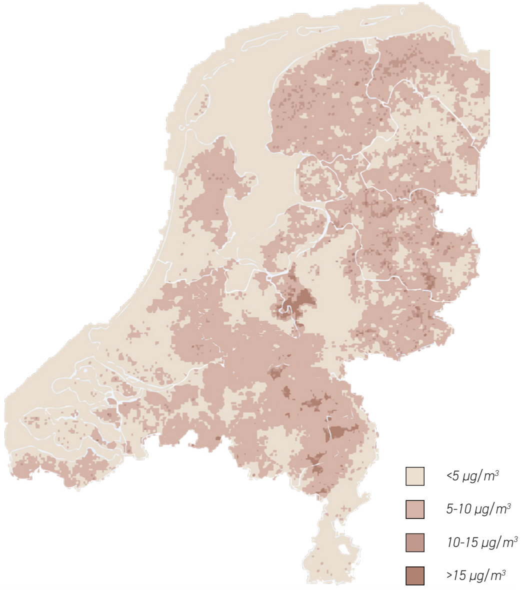


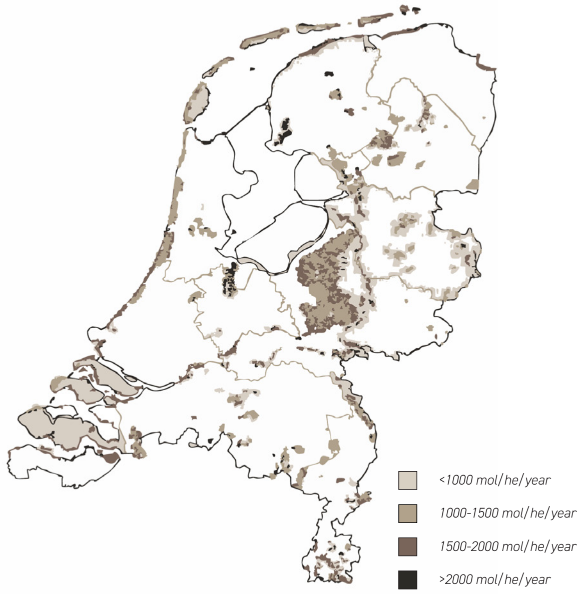

*Fig. 9: Nitrogen cycle*
*Fig. 10: Sensitivity of landscapes (based on Ontspannennederland, z.d.)*


Peatlands
Very sensitive
Stream valley
Sensitive
heath & Forest
Sensitive
Estuaries
Not sensitive

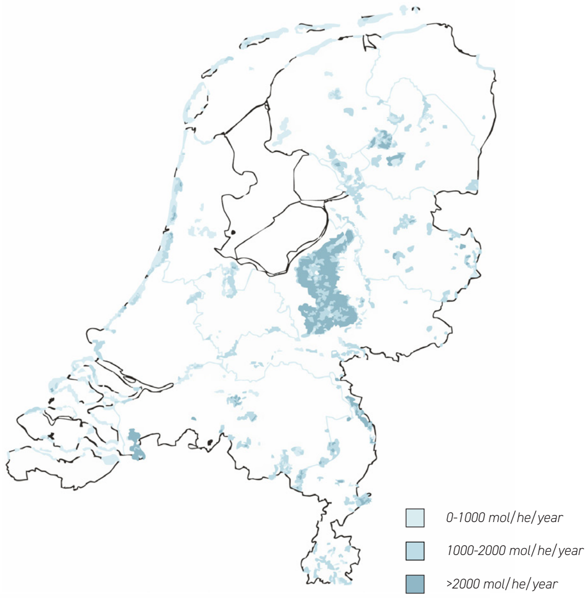

AMMONIA GAS
($NH_3$)
FERTILIZER
($NH_4NO_3$)
AMMONIFICATION
By bacteria and molds
Manure
LIFESTOCK
FOODCROPS
Dead plamt matter
Dead algue



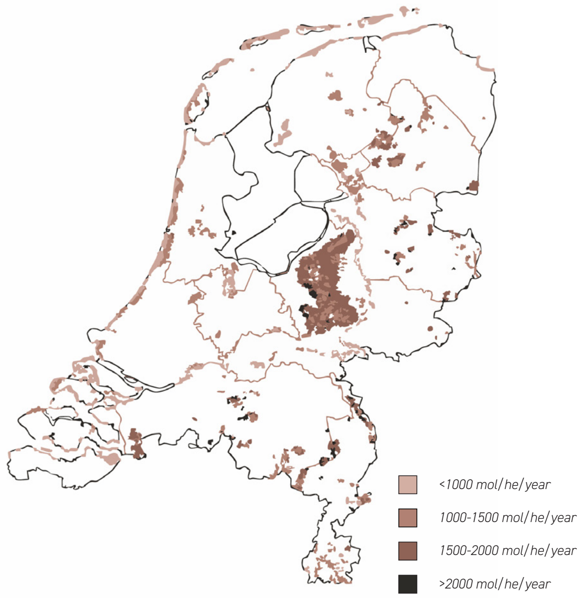

*Nitrogen emission*



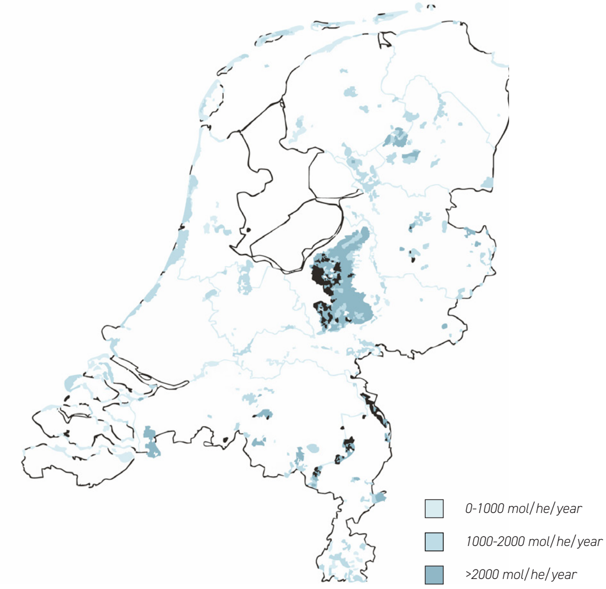

*Critical deposition Natura2000*



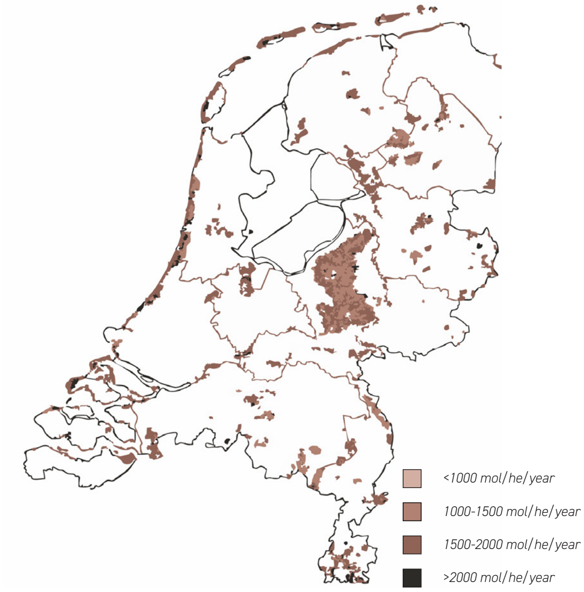

*Nitrogen deposition on Natura2000*




*Exceeding of critical deposition on Natura2000*




*Expected Nitrogen deposition on Natura2000 (2030)*




*Expected Exceeding of critical deposition on Natura2000 (2030)*

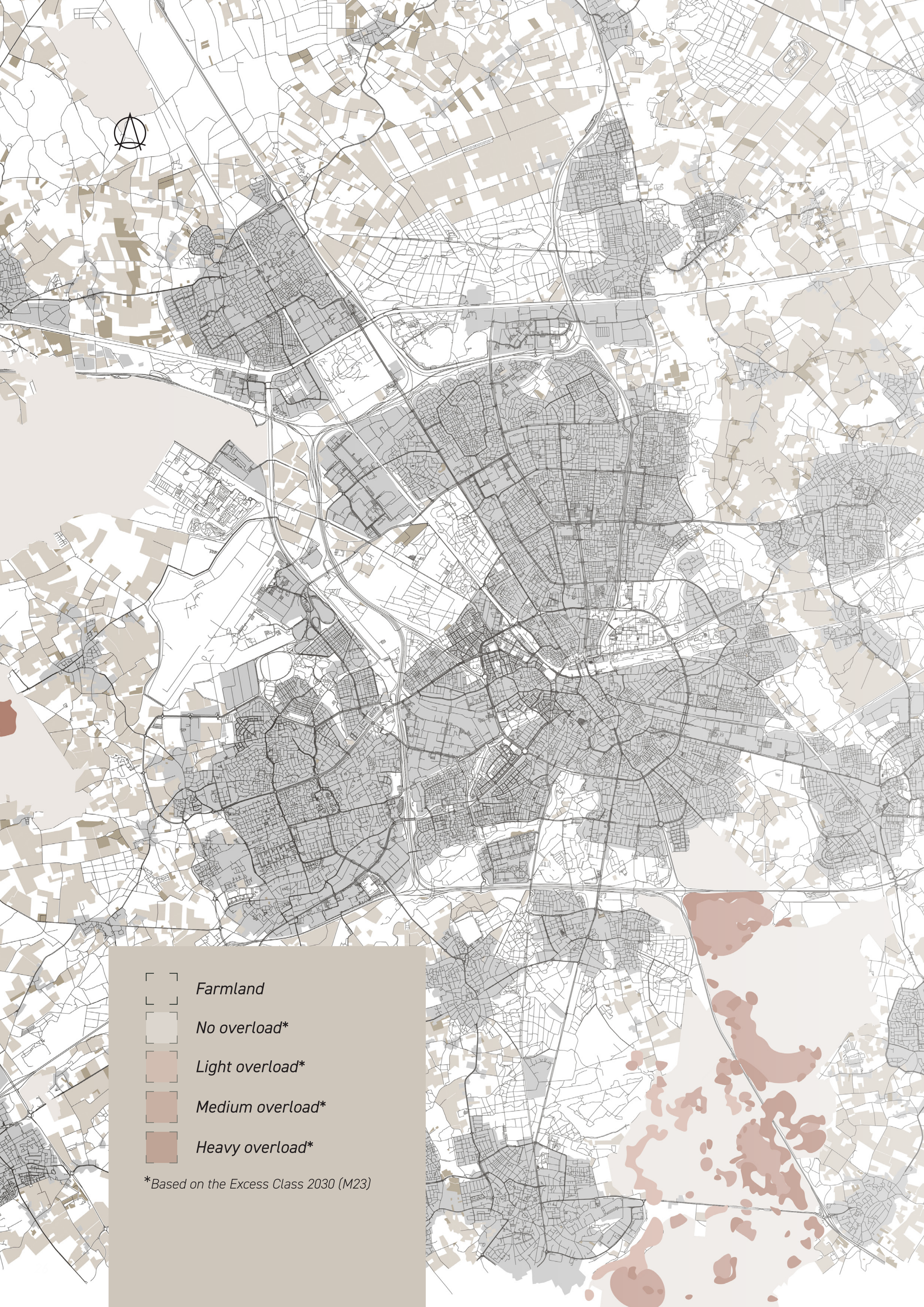
# Territorial Deposition

Nitrogen is a national condition before it is a local one. Roughly two-thirds of deposition in the Netherlands comes from domestic sources, and Dutch agriculture alone accounts for about half of the national total, the single largest source (CLO, 2025). The maps opposite separate the two halves of the problem: where nitrogen is emitted, and where it lands. They rarely coincide. Ammonia travels tens to hundreds of kilometres before settling, so the burden collects in protected nature far from the barns that produced it (CLO, 2025).

North Brabant carries this more than most. Its dense livestock sector makes it one of the country's heaviest ammonia-emitting regions, and the critical deposition value, the threshold a habitat can absorb without degrading, is exceeded across the great majority of Dutch Natura 2000 area (RIVM, 2025). The Stratumse Heide and the valley of the Tongelreep are among the exceeded sites.

The Dommel ties the region together. It rises in Belgium and runs north through Eindhoven to 's-Hertogenbosch, threading past intensive farmland the entire way. What the air deposits, the water collects and carries: the river is both a victim of the surrounding land use and the line along which an intervention can act.

*Fig. 11: Emission & desposition in NL*
*(Rijksinstituut van volksgezondheid en milieu, 2025)*


Farmland
No overload*
Light overload*
Medium overload*
Heavy overload*
*Based on the Excess Class 2030 (M23)

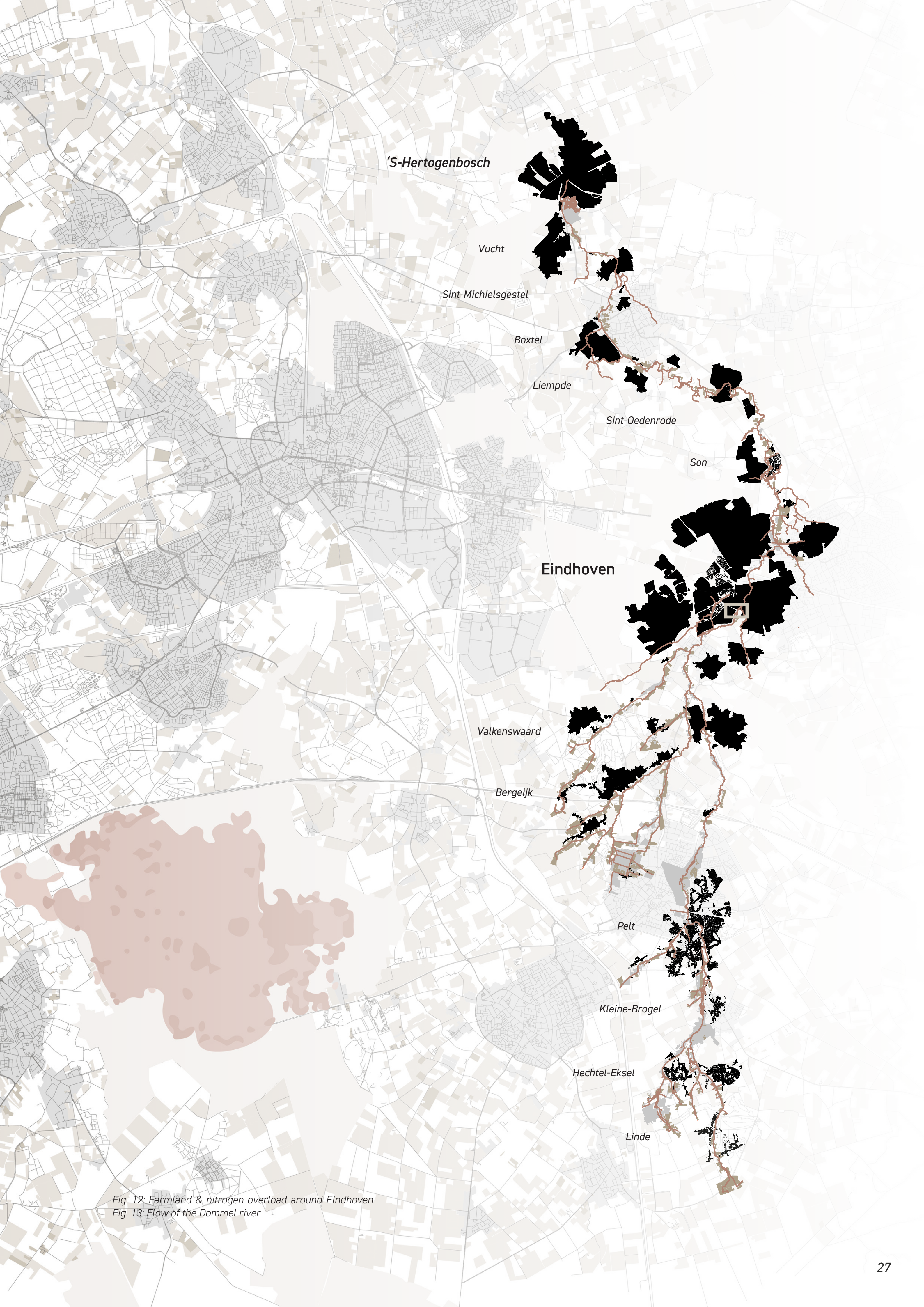


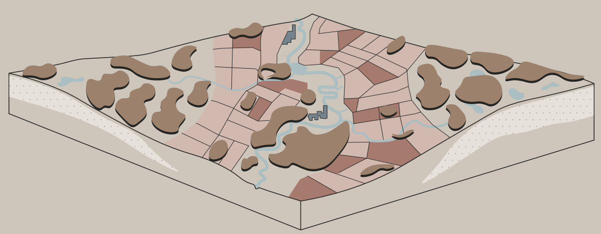

Fig. 12: Farmland & nitrogen overload around Eindhoven
Fig. 13: Flow of the Dommel river

# 19th century stream valley landscape

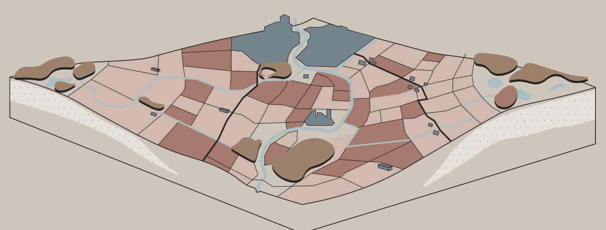
To know what the wetland is restoring, it helps to know what the valley was. Before twentieth-century drainage and fertiliser, the Dommel was not a clean line on a map but a slow, shifting system of water. For roughly a thousand years its character was shaped by watermills: each mill dammed the stream, raised the level upstream, and held water across the valley floor far beyond the structure itself, an effect the authors call the stuwschaduw, the mill's hydrological shadow (De Mars & Bleumink, 2022). Water lingered instead of leaving.

That lingering built a specific ecology. Seasonal flooding with lightly buffered stream water, yearly mowing, and a absence of fertiliser kept the valley floor nutrient-poor (De Mars & Bleumink, 2022). The result was the beekdallandschap: broekbossen, reed and sedge marsh, and species-rich wet hay meadows, blauwgrasland and its specialists, plants that survive precisely because nothing over-feeds them. The poverty of the system was the source of its richness.

Modern drainage reversed the logic. Straightened, deepened channels move water out as fast as possible; the sponge dried, the meadows coarsened, and incoming nitrogen finished what drainage began (De Mars & Bleumink, 2022). The two sketches (tekening) opposite measure the distance between the two states.



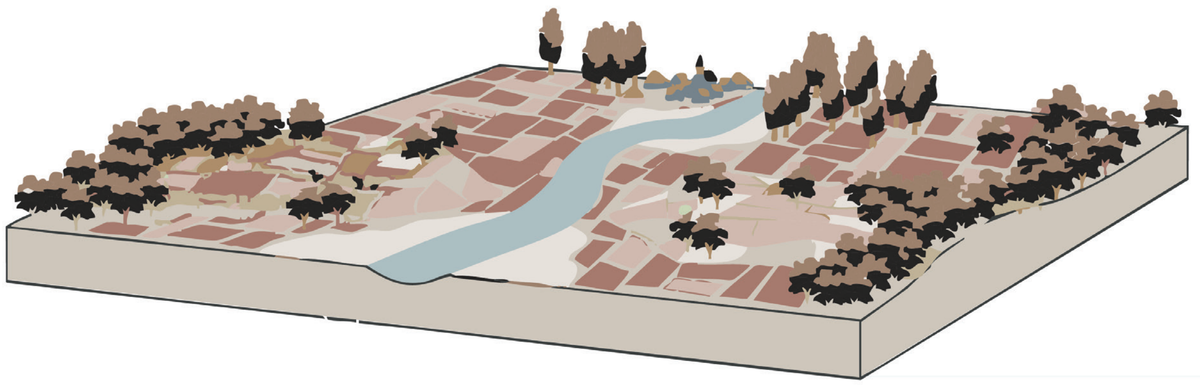
*Historical landscape of Brabant*



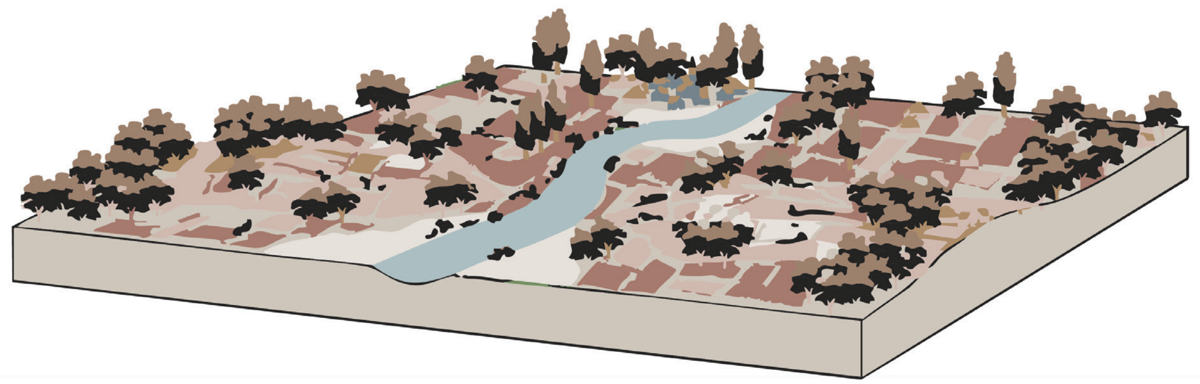
*Current landscape of Brabant*

This is the reference the project reaches back toward as a working ecological target. The mill landscape already proves the principle the design depends on: hold water in the valley, keep nutrients low, and the sensitive stream-valley ecology returns. Current visions for the Dommel pursue the same direction at regional scale (Erisman et al., 2021). The wetland and its reed are one local instance of that larger restoration.

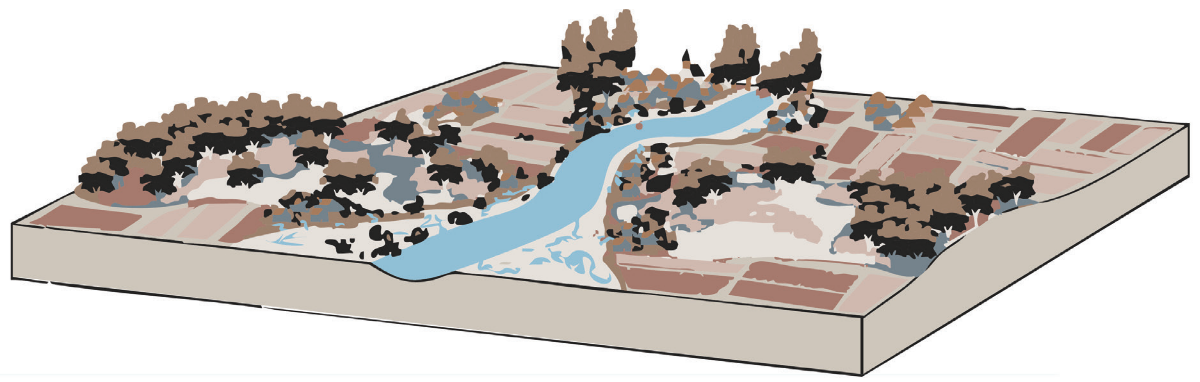
*Fig. 14: Historical & current stream valley landscapes of brabant (based on Klimaatrobuustebeeklandschappen in perspectief, WUR)*
*Fig. 15: Scenarios for the dommel (based on Klimaatrobuustebeeklandschappen in perspectief, WUR)*



*Perspective 1: Changing stream valley landscapes*



*Perspective 2: Inclusive stream valley landscapes*



*Perspective 3: tream valley landscapes of stature*

# N-reduction techniques

No single measure resolves the nitrogen problem, so the question is not which technique is best in the abstract, but which combine into one coherent landscape intervention. The table opposite scores the available strategies against six criteria, a design judgement informed by the literature on each method [citations]. The criteria are what this project has to satisfy: N-reduction, the baseline test of whether a measure actually removes nitrogen; spatial integration, whether it takes landscape form rather than hiding as equipment; public awareness, whether it can be seen and understood by visitors; material production, whether it yields a usable output for the building; Dommel compatibility, whether it suits a low-gradient Brabant stream valley and the historical water logic of 2.4; and scalability, whether it works as part of a regional network.

Read across these, four strategies stand out and stack into a single system. Buffer strips intercept runoff at the field edge; floodplain restoration slows the stream and reactivates the valley's water-holding capacity; constructed wetlands combine denitrification, plant uptake and landscape while producing reed (De Mars & Bleumink, 2022) biomass harvesting removes the captured nitrogen permanently and turns it into material. Together they form a sequence, field edge, floodplain, wetland, harvest, that filters water, rebuilds the nutrient-poor valley ecology, and yields the reed the building is made from. That sequence is the basis for the integrated design in Chapter 3.

*Fig.16: Nitrogen-reduction mechanisms (Trepel & Palmeri (2002); Ndegwa et al. (2008); Montes et al. (2013); Zak et al. (2020); Liu et al. (2020); Kim & Isaac (2022); Boezeman et al. (2023); Legesse et al. (2023); Ali et al. (2025); Laasri (2025).) Compatibility, public-awareness, and scalability assessments are the author's own.*

| Category | Strategy | |
|---|---|---|
| Source reduction strategies | Lifestock reduction | *The governme cially near Na nently remove* |
| | Food modification | *Lifectock feed nia emissions* |
| | Low-emission stables | *Technically m systems* |
| Technical mitigation | Ammonia scrubbers | *Industrial filte* |
| | Manure processing | *Manure is pro or nitrogen co zer or industr* |
| | Algue bioreactors | *Algal growth* |
| Agricultural transition | Agroforestry | *Integrates tre improve nitro* |
| | regenerative agriculture | *Soil restoratio imput through processes* |
| | Precision agriculture | *Use of sensor fertilization to application.* |
| | Buffer strips | *vegetated wat* |
| Landscape systems | Rewetting peatlands | *Raising groun nitrogen mine from peat soil* |
| | Floodplain restoration | *Slowing water* |
| | Constructed wetlands | *Filter water th plant growth* |
| Resouces | Biomass harvesting | *Removing nitr plantmatter* |
| | Paludiculture | *Wet agricultur* |
| | Embodied nitrogen materials | *Nitrogen abso applied in the* |

| Summary | N reduction | Spatial integraton | Public awareness | Material production | Dommel compatibility | Scalability |
|---|---|---|---|---|---|---|
| ent buys out farmers, espe- tura 2000 areas, and perma- es livestock and permits. | High<br>removes major emission source | Low<br>Removes activity | medium<br>Politically/ publicly visible | - | Medium<br>Relevant in Brabants livestock intensity | Medium<br>Politically and economically difficult |
| is changed to reduce ammo- | Medium<br>Directly removes major emission source | - | Low<br>invisible for non-farmers | - | Medium<br>Relevant in Brabants livestock intensity | High<br>Broadly applicable |
| odified barns and floor | Medium<br>Reduces stable emissions | Medium<br>Integrated, but isolated technical design | Low<br>Hidden in stable architecture | - | Medium<br>Relevant in Brabants livestock intensity | Medium<br>Costly and tech. dependent |
| ration systems | High<br>Effective local filtration | Low<br>Isolated technical object | Low<br>Generally hidden | Low<br>Recovered materials possible | Low<br>Too small flowrate for scale | Medium<br>Costly |
| cessed to extract ammonia ompounds for reuse as fertili- ial input. | Medium<br>Reduce excess N | Low<br>Centralized industrial process | Low<br>Generally hidden | medium<br>Fertilizer & Energy recovery | Medium<br>Relevant in Brabants livestock intensity | Medium<br>Logistical infrastructure required |
| efficiëntly absorbs nutrients | High<br>Plant growth | Low<br>Usually enclosed, & tech. with exeptions | Medium<br>Can be integrated visually | High<br>Biomass & heat production | Low-Medium<br>Less suited to dispersed water systems | Low<br>technically intensive |
| es, crops, and animals to gen uptake and soil health. | Medium<br>Improves N-retention | High<br>Restructures agricultural landscapes | Medium<br>Visible landscape transformation | medium<br>Timber and biomass production | Medium<br>Applicable but less water focused | Medium<br>Long term land transition |
| on and reduced fertilizer n natural ground fertilisation | Medium<br>Less fertilizer use | Medium<br>Alters agricultural practices | Low<br>Generally hidden | Low<br>No direct new material stream | Medium<br>Broadly applicable in land | Medium<br>Depends on farmer adoption |
| s, GPS, AI, and data-driven reduce excess nitrogen | Medium<br>Less fertilizer use | Low<br>Only tech. optimisation | Low<br>Invisible data system | - | Medium<br>Applicable to intense agriculture | High<br>Broadly applicable |
| ter edges | Medium<br>Capture runoff before waterways | High<br>Integrates with waterways | Medium<br>Small landscape transformations | Low<br>Limited biomass potential | High<br>River edge applicability | High<br>Broadly applicable |
| dwater levels to reduce ralization and emissions s | Medium<br>Reduces oxidation & mineralisation | High<br>Restores hydrological systems | high<br>Visible landscape transformation | Low<br>Limited biomass potential | Low<br>Relevant in wet lowlands | medium<br>Dependent on land availability |
| r flow for more denitrification | High<br>Reduces oxidation & mineralisation | High<br>Restores hydrological systems | High<br>Visible landscape transformation | medium<br>Biomass potential | High<br>Allignes with stream valley logic | medium<br>Expandable along river corridors |
| hrough dentrification and | High<br>Combines denitrification and plant uptake | High<br>Integrates water, ecology, and landscape | High<br>Visible landscape transformation | High<br>Reed biomass potential | High<br>Allignes with stream valley logic | High<br>Can operate as scaled network |
| rogen through harvested | High<br>nutrient uptake by plants | medium<br>Depends on landscape system | medium<br>Visible landscape transformation | High<br>Material output | High<br>Works with stream valley ecology | Medium<br>Season dependant, Labour heavy |
| re on rewetted land | High<br>nutrient uptake by plants | High<br>Productive landscape | High<br>Visible landscape transformation | High<br>Biomass output | High<br>Works with stream valley ecology | Medium<br>Requires major land-use transition |
| rbing minerals & chemicals living environment | Low<br>Material dependent, mostly indirect | - | High<br>Can communicate N issues through material use | High<br>Material output | Low<br>Weak territorial specificity | Low<br>Experimental systems |

***Where***

*This chapter turns the territorial research into a real place. It explains why this exact spot in the Dommel valley was chosen, and how ecological, hydrological, and social flows already meet here. The site is read not as a neutral plot but as a condenser, a point where the project's separate themes are already gathered on the ground.*

# 3

# Site as Condenser

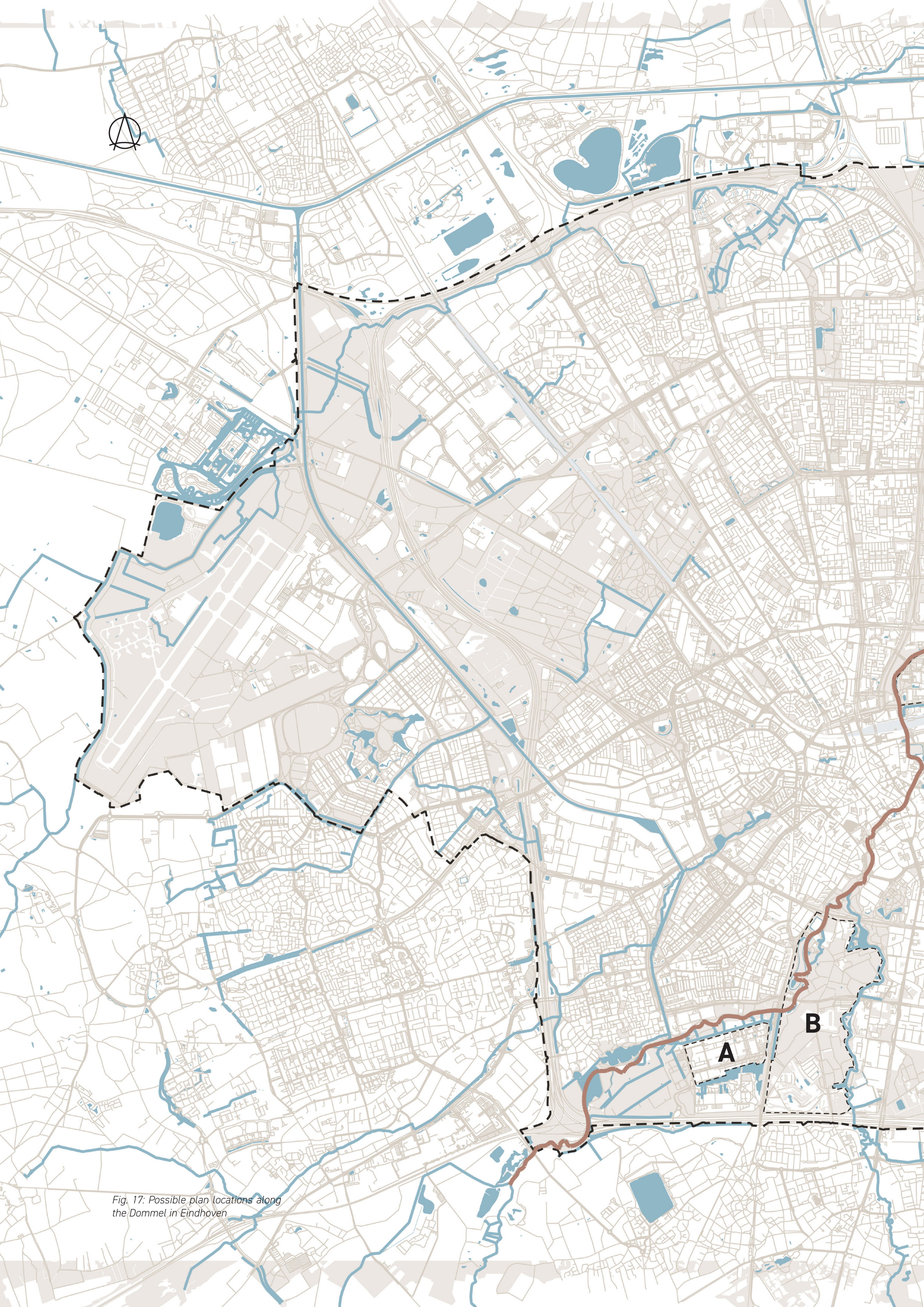
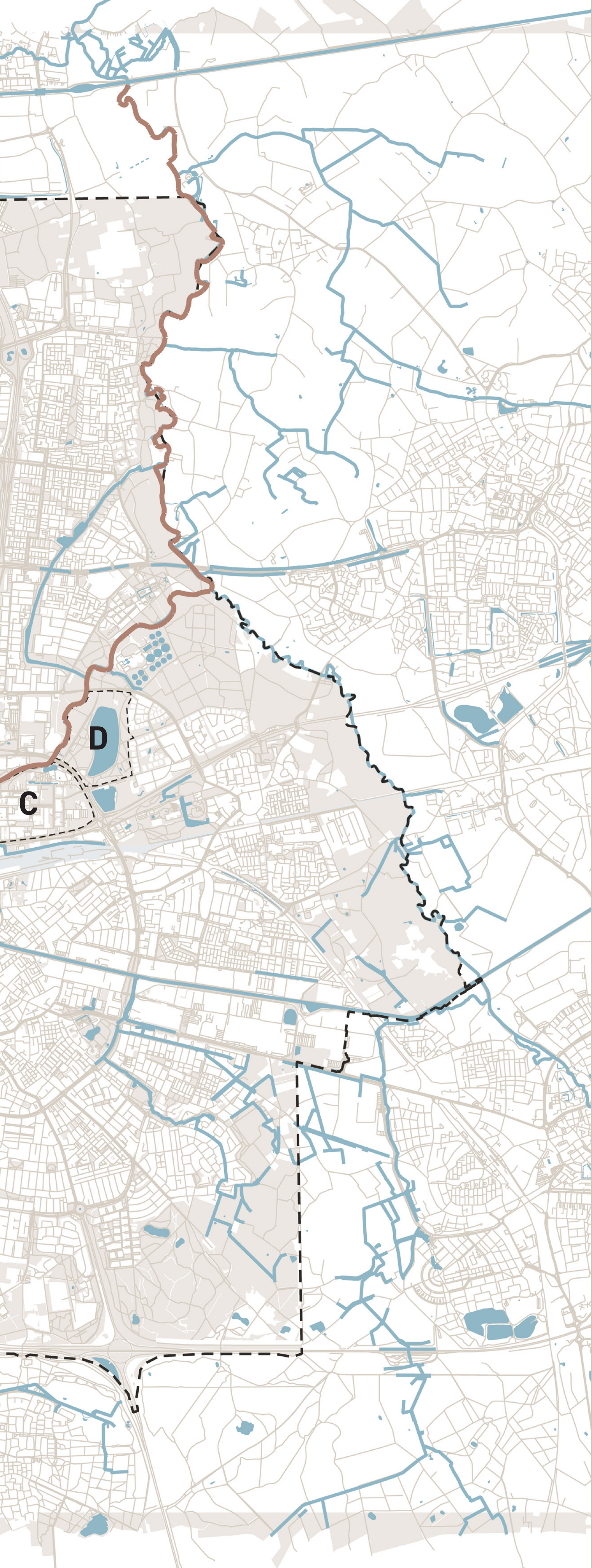



*Fig. 17: Possible plan locations along the Dommel in Eindhoven*




Within Eindhoven, where the Dommel runs through the city, four sites were considered, each meeting the baseline criteria; space, , neighbouring public functions, and good public-transport access.

A: High Tech Campus. Strong research culture and visibility, well connected, and close to the river's southern reach; a natural fit for the project's research dimension, though tightly built and short on landscape.

B: Genneper Parken. Close to the city centre, already part of a regional nature network, with the space, water infrastructure, and adjacent public functions the project needs.

C: TU Eindhoven campus. Direct access to research and a large public, with the Dommel running through it; ideal for engagement but constrained for a working wetland.

D: Karpendonkse Plas. An existing water-and-recreation landscape with room and an established public, but further from the river's agricultural load and the educational cluster.

Genneper Parken (B) is selected: it combines centrality, an existing nature network, available land and waterworks, and a cluster of related public functions that no other site brings together in Eindhoven.

Genneper Parken splits in two. Its southern half is largely sport; its northern half, where the Dommel enters, is where the park turns to nature. The north already holds three functions the project speaks to directly. The prehistoric village builds with thatch and reed-clay infill and draws a steady public, a living demonstration of the same material the project industrialises. The stadsboerderij brings both visitors and a small agricultural nitrogen source. And VONK park, currently being built, is a new public landscape this design could form part of. The themes are already gathered here.

The site itself sits between VONK park and the river: a mostly empty stretch of grass fields, a disused driving school, and a large asphalt plate. It is the park's leftover edge, sealed, underused, and directly against the water the project needs.


*Fig. 18: Highlights of Genneper park north*

Fig. 19: Routes & structures on plan location

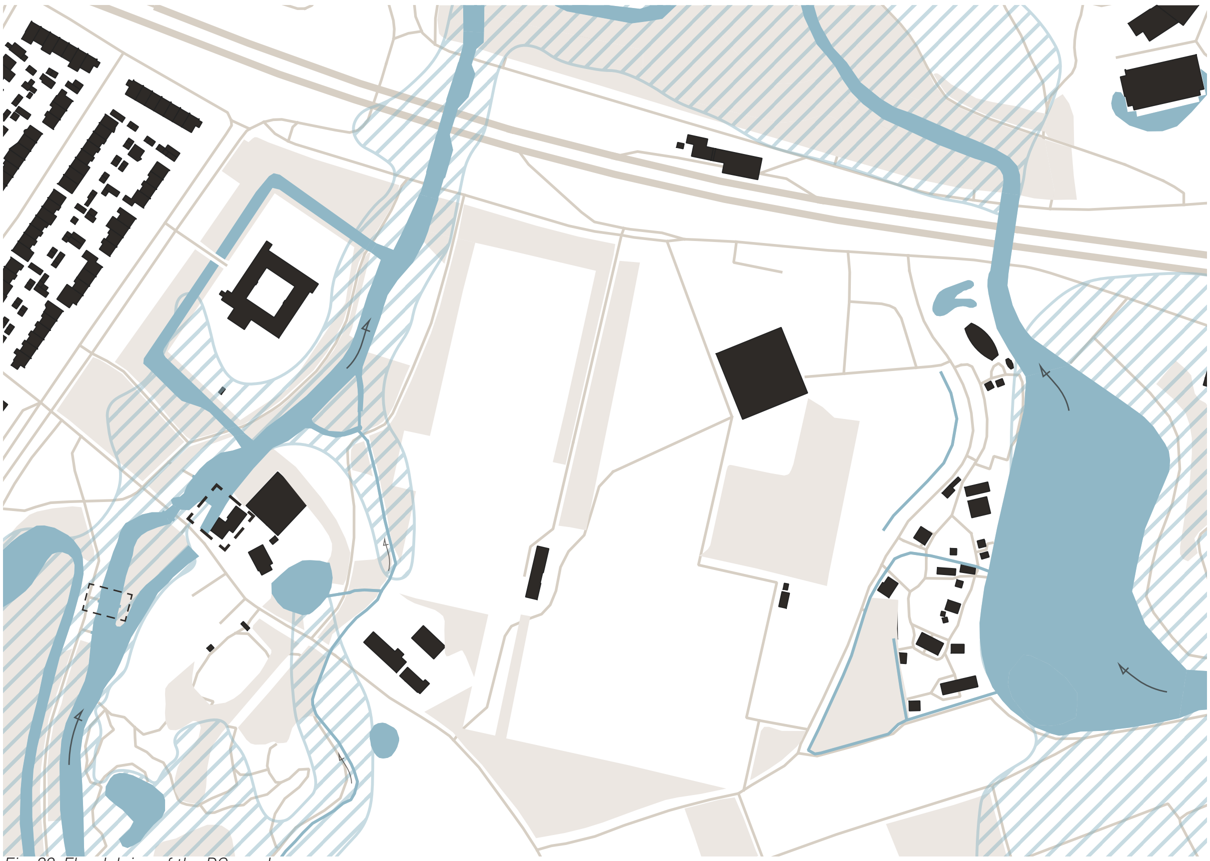


Fig. 20: Floodplains of the DOmmel

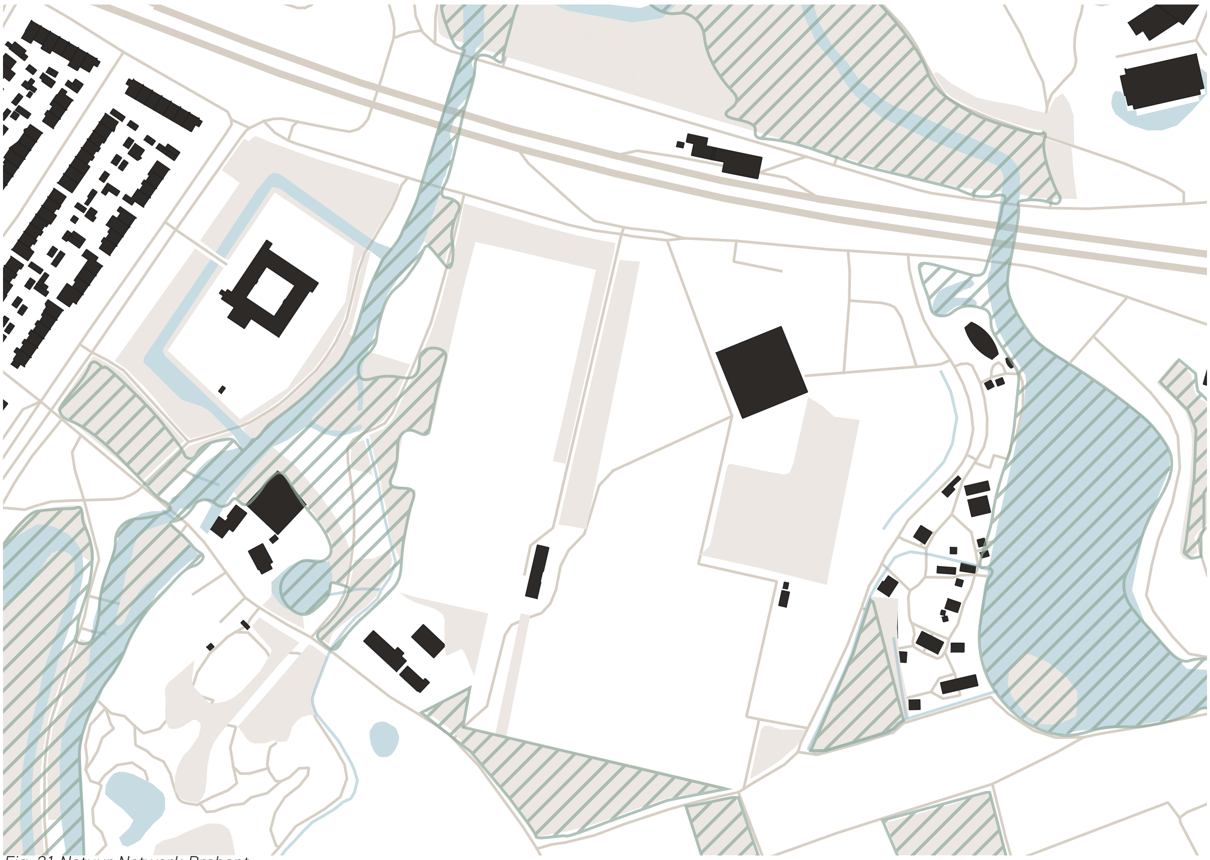


Fig. 21 Natuur Netwerk Brabant

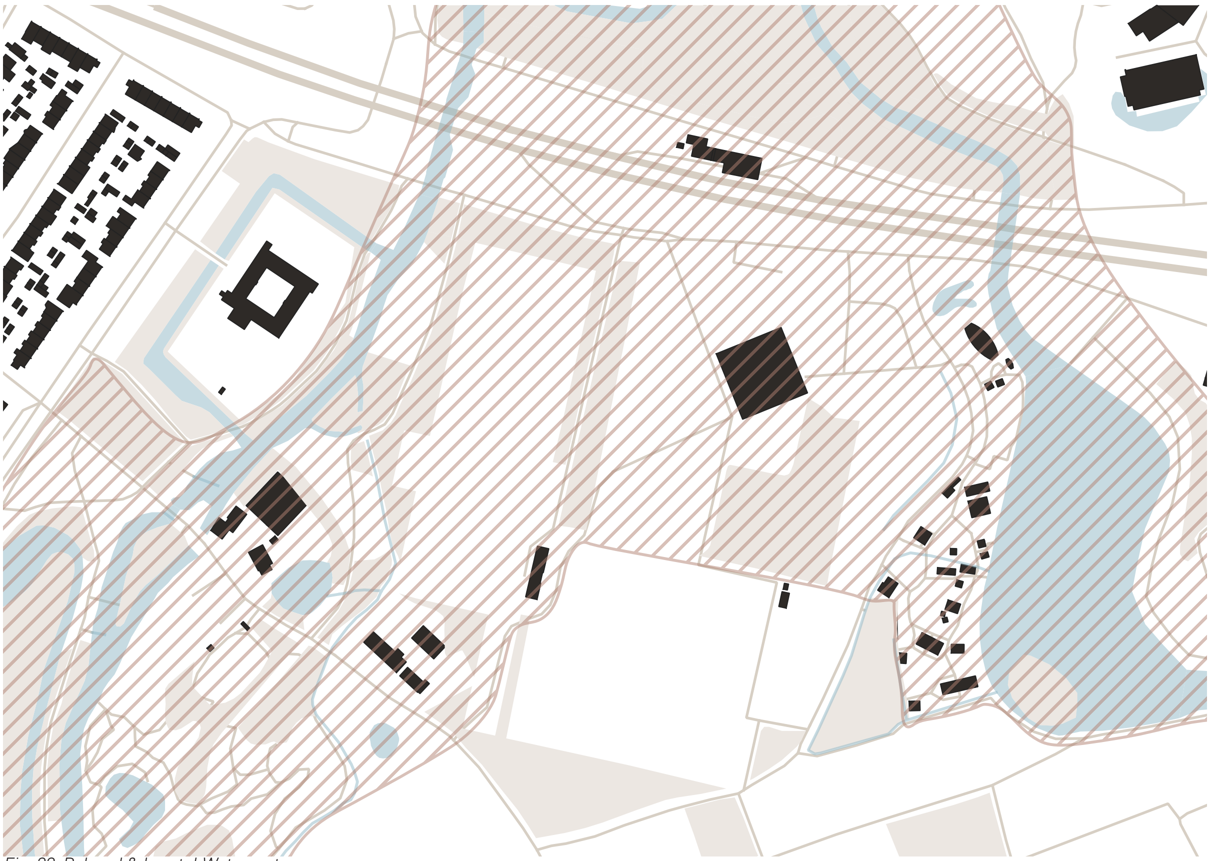
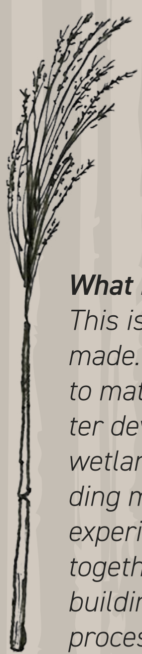


Fig. 22: Behoud & herstel Watersystemen



***What if***

*This is where the project is made. Working from landscape to material to building, the chapter develops the constructed wetland, tests reed as a building material through physical experiment, and brings the two together into one architecture, a building grown from, and built to process, the landscape it sits in.*

4

# Research & Design

## Wetland as productive system

*Wetlands as metabolic infrastructures*
*Constructed wetland typologies*
*Reed ecologies and seasonal cycles*
*Harvesting and productive output*

## Reed as biomaterial

*Reed as regenerative building matte*
*Historical reed architecture*
*Reed across architectural layers*
*Experimental reed composites*

## Architecture as interface

*Typological positioning*
*Architectural Precident*
*Program of requirements*

# Wetlands as metabolic infrastructures

A constructed wetland is an engineered version of a natural one: a shallow, planted basin that water passes through slowly, so that biological and microbial processes can act on what it carries. Here it treats nitrogen-loaded water drawn from the Dommel system.

Wetlands remove nitrogen through several pathways, but only two remove it permanently rather than shuffling it between forms (Vymazal, 2007). The dominant one is microbial: bacteria living on the reed's roots and in the sediment first nitrify ammonia, then denitrify it into $N_2$ gas, which leaves harmlessly to the air it came from. This coupled nitrification–denitrification accounts for the majority of nitrogen removed (Lee et al., 2009).

The second pathway runs through the plant. Reed takes up nitrogen and stores it as biomass, but this is only storage until the reed is cut. Harvested, that nitrogen leaves the system as material; left standing, it returns to the water as the plant dies back (Vymazal, 2007). So the wetland does not store nitrogen. It redistributes it, venting most to the air, and routing the rest into a crop the building is made from.

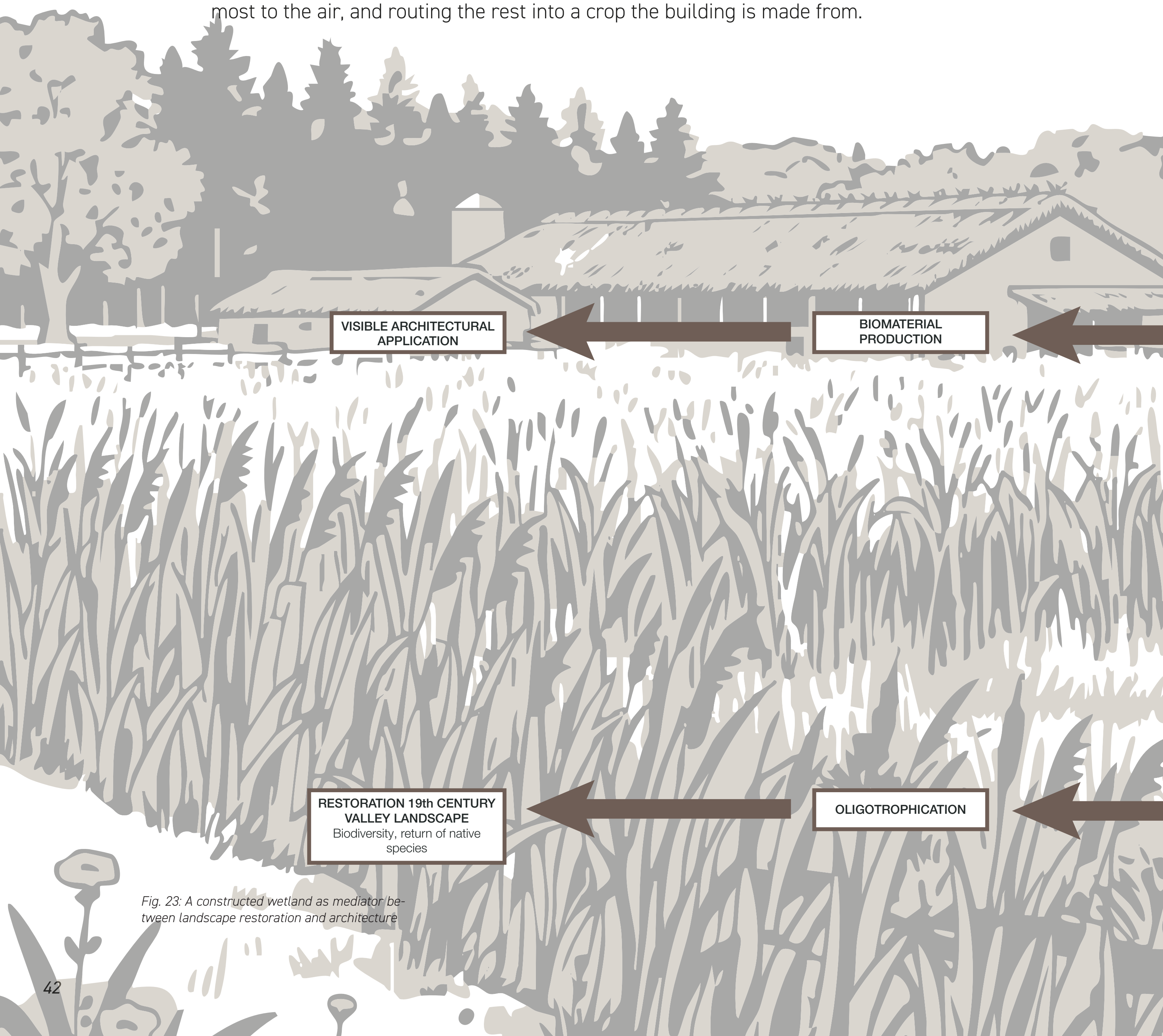



*Fig. 23: A constructed wetland as mediator between landscape restoration and architecture*

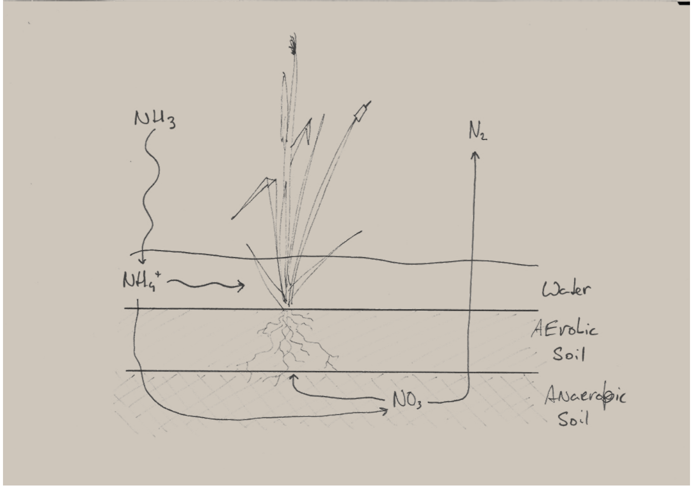
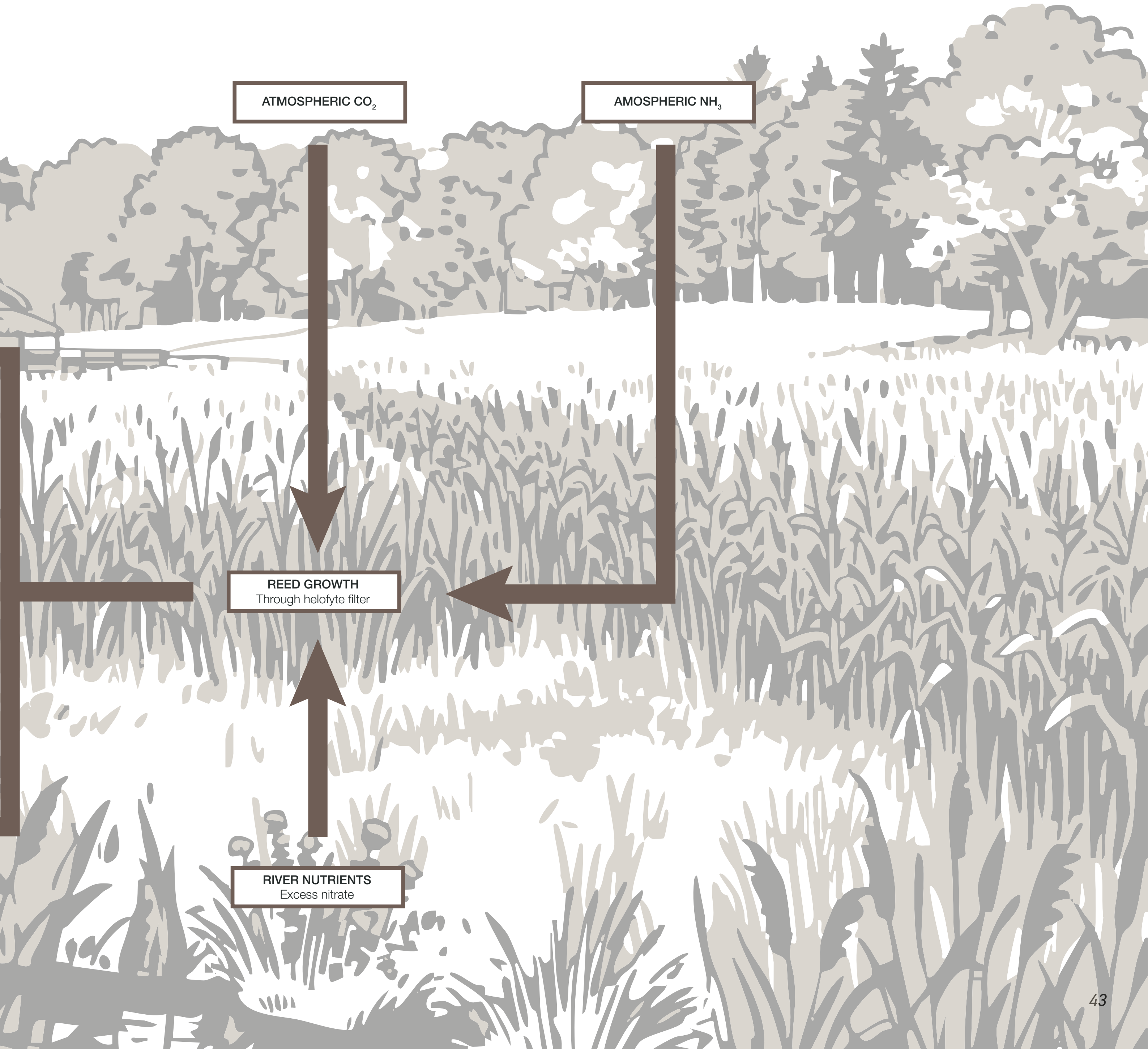



*Fig. 24: How the rhizome network bacteria turn ammonia into harmless $N_2$*



# Constructed wetland typologies

The two paths to nitrogen reduction  need opposite conditions. Nitrification needs oxygen; denitrification needs its absence (Lee et al., 2009). No single basin provides both well, which is why the design pairs two wetland types. Surface-flow wetlands, with water moving openly above the bed, oxygenate readily and read clearly as landscape. Sub-surface-flow wetlands, with water passing through a planted substrate, hold the anaerobic zones denitrification depends on. Combining them in sequence lets water move through aerobic and anaerobic conditions in turn, the alternation that drives removal (Lee et al., 2009).

Several principles shape the layout. A sedimentation basin at the inlet drops sediment before it can clog the reed bed. A long, narrow footprint, roughly a 4:1 length-to-width ratio, and curvilinear edges lengthen the water's path and contact time. Weirs set and vary the water level, switching beds between wet and dry. A distributed series of smaller wetlands along the stream outperforms one large basin, spreading treatment and risk across the valley rather than concentrating it (Urban Green-blue Grids, z.d.).

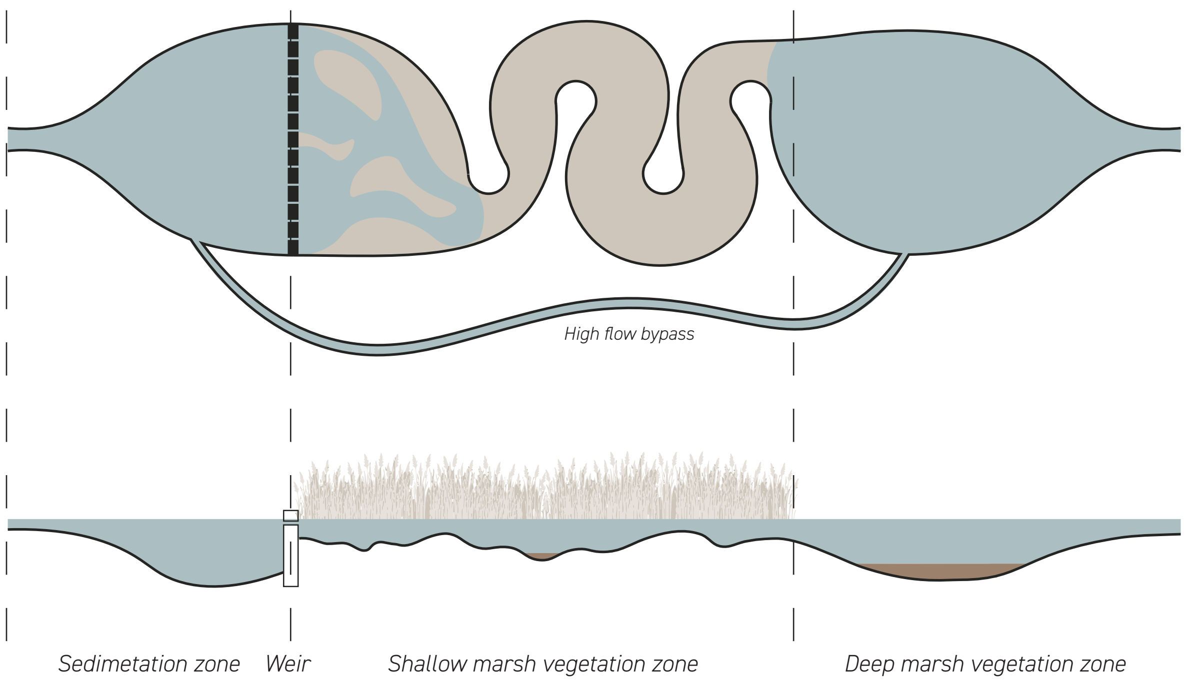
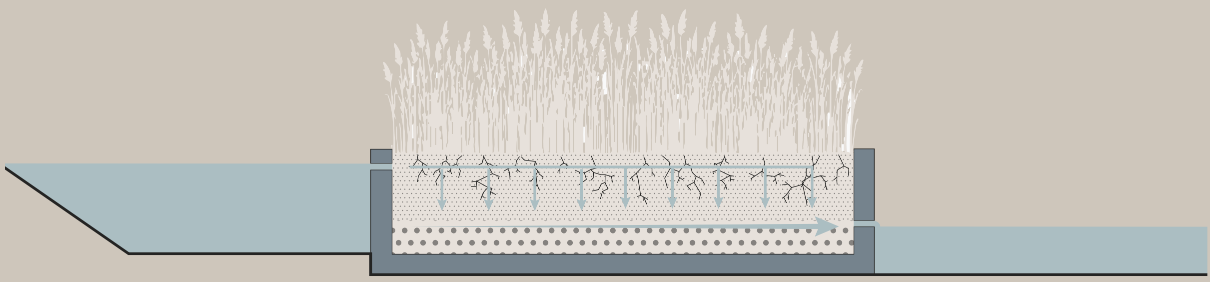
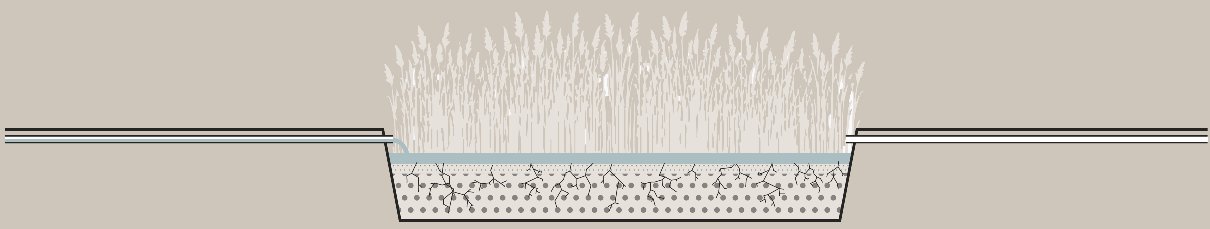


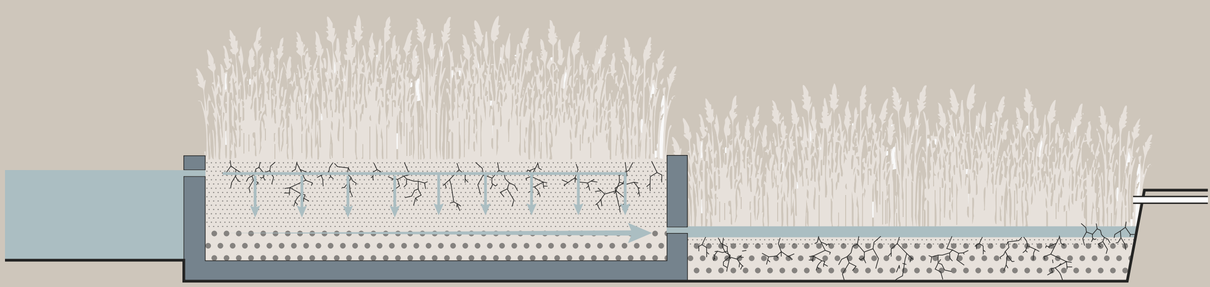

*Fig. 25: Typical constructed wetland scematic (based on urbangreenbluegrids)*
*Fig. 26: Three sections of types of constructed wetland*



*Sub-surface constructed wetland*



*Surface flow constructed wetland*



*Hybrid constructed wetland*

# Reed ecologies and seasonal cycles

The wetland's product depends on what grows in it, and on when. Common reed, Phragmites australis, is both the natural coloniser of these conditions and the one the design selects: It tolerates high nutrient loads, grows fast, and spreads through underground rhizomes into dense, self-maintaining stands, among the most productive emergent species, accumulating roughly 30–60 g of nitrogen per m² in its above-ground biomass, the part available for cutting (Vymazal, 2007). It is also native to exactly the wet, low-gradient conditions the wetland recreates, which ties the productive system back to the historical valley ecology of Chapter 2.

Its value here follows its calendar. Reed emerges in spring and accumulates biomass and nitrogen through summer. In autumn it senesces: nutrients begin withdrawing from stem to rhizome, and the standing crop dries. Cut in winter, the dry stems carry the least moisture and the most structural value, and crucially, this is when cutting removes nitrogen from the system rather than letting senescence return it to the water (Vymazal, 2007).

The timing resolves a conflict, too. Reedbeds are breeding habitat for marsh birds from roughly April to August. A winter harvest falls entirely outside that window, so the period when the wetland is most ecologically sensitive is also the period when no one cuts, and, by extension, when public access to the reedbeds is restricted.

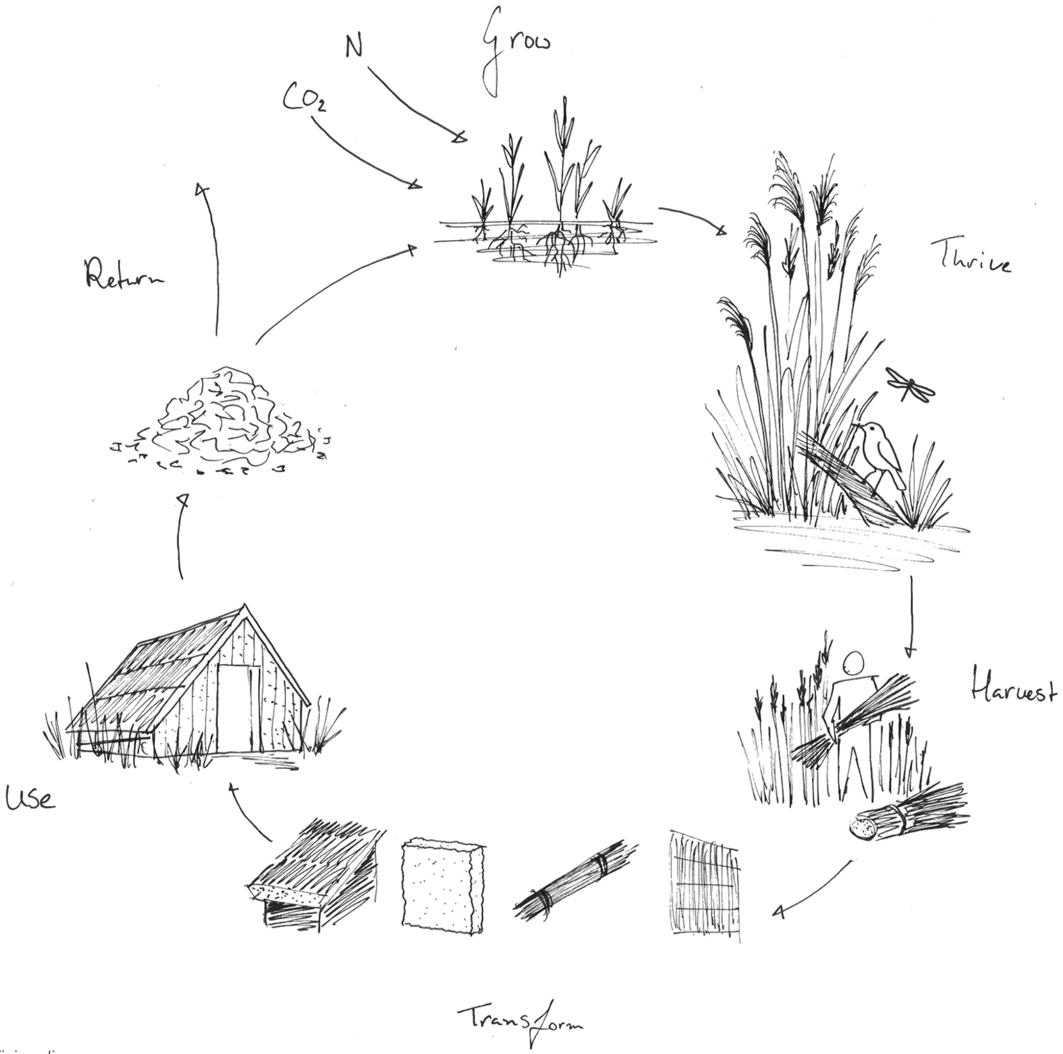



*Fig. 27: Vision diagram*

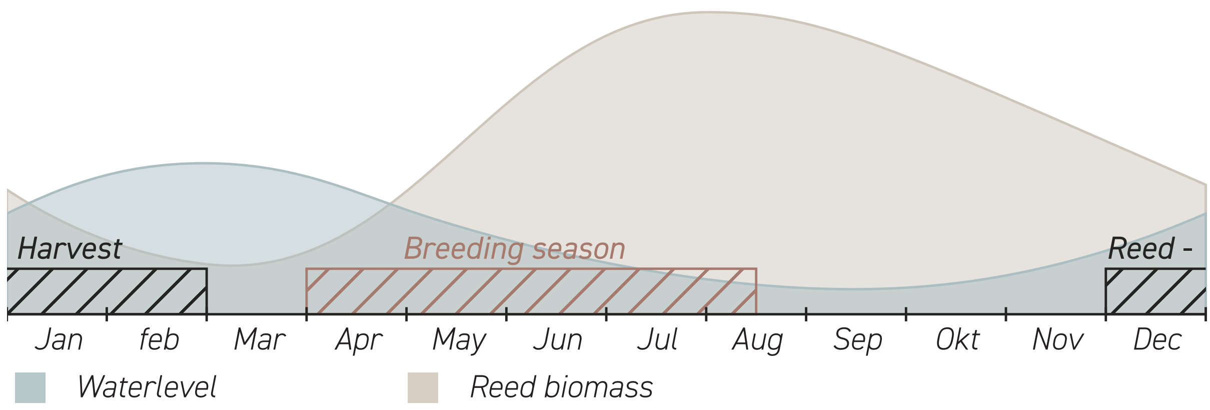



*Fig. 28: Phenological calendar of a productive wetland*

# Productive output

Harvesting is the hinge of the system, but it is worth being precise about what it does and does not achieve. The scale of the problem is large: the Dommel carries roughly 5 mg/L of total nitrogen at a mean flow of 1.73 m³/s, which amounts to about 747 kg of nitrogen per day, or some 273 tonnes a year. As an illustration of that load, it is comparable to the total nitrogen excreted annually by around 2,400 dairy cows (CBS, 2025).

Against that figure, cutting reed is a poor filter. At an uptake of 30–60 g N/m², harvesting the reed removes only an estimated 5–10% of the nitrogen the wetland processes. Removing the river's full annual load through harvest alone would demand an unworkable area of reedbed. The bulk of removal is not the plant's work but the microbes': denitrification vents most of the nitrogen as N2 regardless of whether a stem is ever cut (Lee et al., 2009).

Sized on whole-system removal rather than harvest, the numbers become spatial in a useful way. At a design removal rate of roughly 5200 kg N/ha/yr (113 cows), treating the load implies on the order of 52 ha of wetland distributed along the valley, not one basin, but the network described earlier.

Harvesting earns its place for two other reasons. It makes the plant's share of removal permanent, exporting summer's uptake as cut material instead of returning it to the water (Vymazal, 2007). And it yields the reed itself: an annual winter crop of dry, structural stems from the same beds that clean the water. That output is what the architecture is built from, and the subject of the next subchapter.

To put that yield in built terms, a single 2 ha cell of the network produces roughly 20–24 tonnes of dry reed each year. At about 30 kg/m², that is enough to thatch some 700–800 m² of roof annually; the equivalent of around five average houses, and comfortably more than the building to be designed requires.

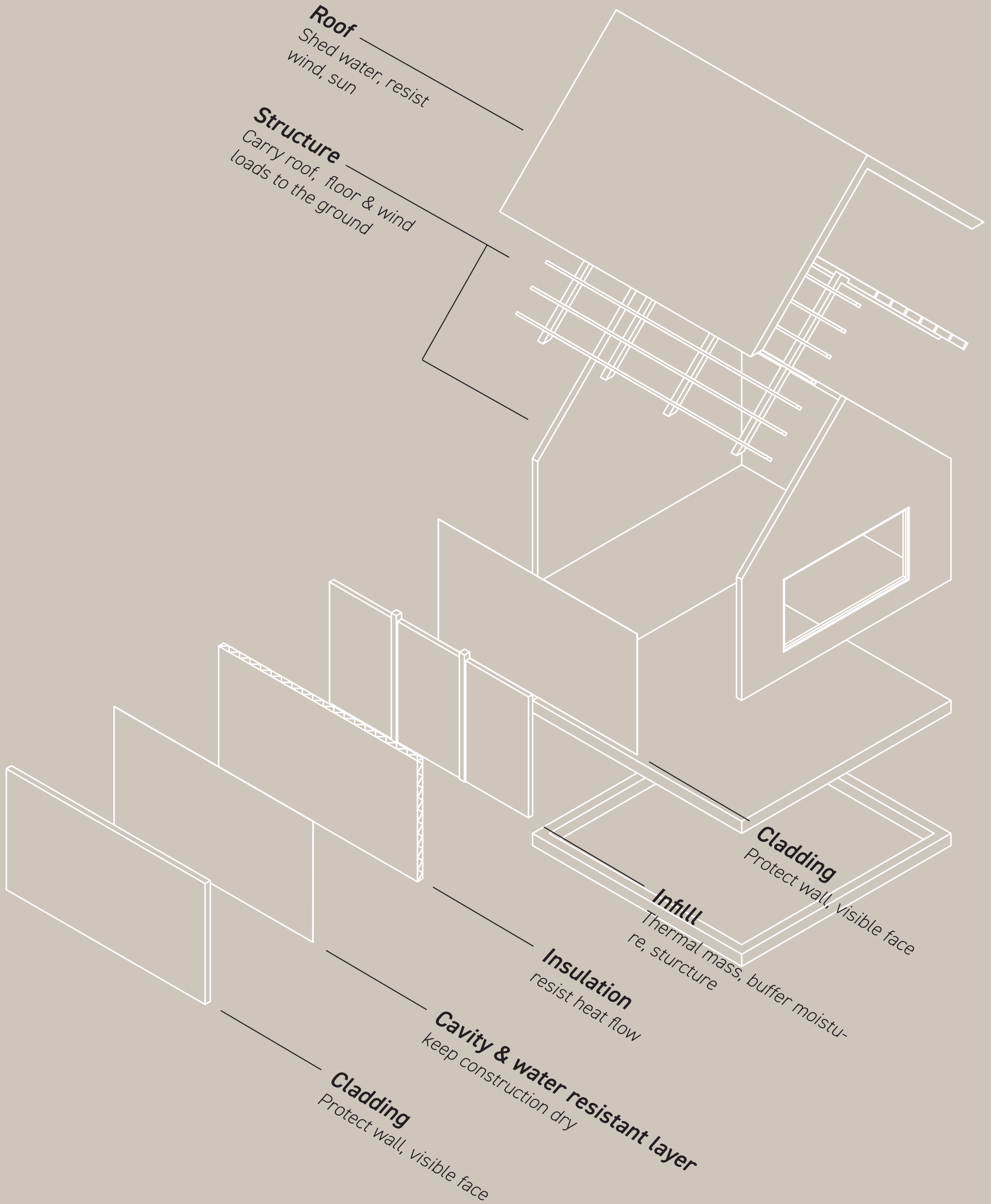
# Reed as regenerative building matter

A building is not one material problem but many. Each layer does a different job and asks for a different performance: the roof and façade shed water, the insulation resists heat flow, the structure carries load, interior finishes buffer moisture. Conventionally each of these is a different industry and a different supply chain. The premise here is narrower and stranger, that a single plant, harvested from the wetland next to the building, can be processed into most of them.

Reed earns this through a useful range of behaviours, varying with how it is worked. Whole stems, long and naturally water-shedding, are the basis of thatch. Dense bundles act in compression and carry load. Hollow stems and loose fibre trap air and insulate. Shredded fibre, compressed with a binder, forms panels. The plant's high silica content makes the stem surface hydrophobic, which is part of why thatch sheds rain (Malheiro et al., 2021). Loose and compressed reed reach thermal conductivities around 0.06–0.08 W/m·K, comparable to conventional bio-based insulation (Malheiro et al., 2021; Bakatovich et al., 2022).

Two properties matter most for the argument of this thesis. Reed is renewable on an annual cycle and stores carbon as it grows, so its embodied impact is low and its supply continuous (Malheiro et al., 2021). And it is biodegradable, which the durability literature frames as a liability, since reed is susceptible to rot when held wet (Malheiro et al., 2021). This project treats that liability as a design condition rather than a flaw, a point the façade returns to. The following sections test, layer by layer, what reed can actually do.

*Fig. 29: relevant simplified layers of a standard building*



Roof
Shed water, resist wind, sun
Structure
Carry roof, floor & wind loads to the ground
Cladding
Protect wall, visible face
Infilll
Thermal mass, buffer moistu-re, structure
Insulation
resist heat flow
Cavity & water resistant layer
keep construction dry
Cladding
Protect wall, visible face

# Historical reed architecture

Reed building is not a novelty to be invented but a tradition to be read. Wherever wetlands met settlement, architecture grew directly out of the reedbed, from the Mesopotamian marshes to the thatched farmhouses of the Netherlands, where Phragmites roofs are still a living craft. These traditions already solved, empirically, some of the problems this project faces: how to span with bundles, shed water with stems, and insulate with fibre. They are read here not as heritage images but as a catalogue of techniques, mapped to a building layer the design has to resolve.

*Fig. 30: thatched roo in the prehistorc village in Gennerparken (Prehistorischdorp.nl, z.d.)*

***Thatched roofs***

*The thatched roof is a deeply rooted building tradition in the Netherlands, where bundles of reeds harvested from the river delta landscapes were layered densely over timber frames to form weather-tight coverings. The natural hollow structure of each reed stalk makes thatch a insulating and durable roofing material.*

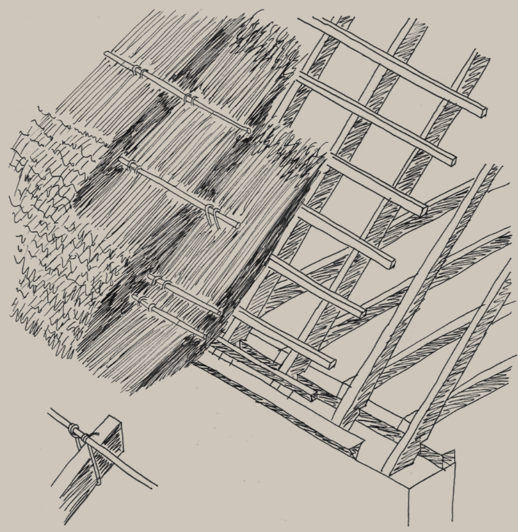


*Fig. 31: thatched roof  buildup sketch*

Fig. 32: Interior of a Mudhif (designedinIraq, z.d.)

*Fig. 32: Mudhif  structure sketch*

***Mudhif***

*The Mudhif is a traditional ceremonial reed house built by the Marsh Arabs of southern Iraq, where bundled reeds harvested from the surrounding marshes are bent into arched structural portals. This building tradition demonstrates how reed, used purely through bundling and bending, can form a complete load-bearing architectural system. (ArCHIAM, 2025)*

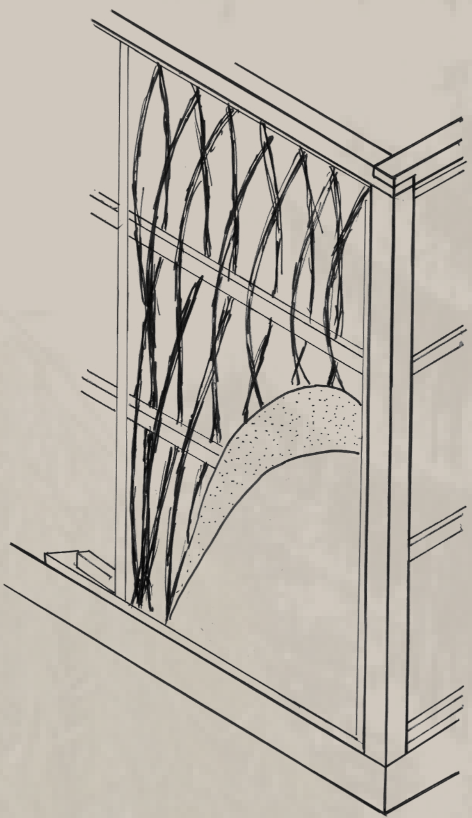


Fig. 33: Wattle and daub buildub sketch

***Wattle and daub***

*Wattle and daub is one of the oldest building techniques known, in which a woven lattice of reeds is packed and plastered with a mixture of clay, soil and straw to form solid walls. This combination of flexible reed framework and compressive clay infill creates a lightweight yet thermally effective wall system.*

Fig. 34: Wattle and daub house (Motherearthnews. z.d.)

# Experimental tectonics - structure

The structural starting point is the Mesopotamian mudhif: a hall built entirely of reed, its roof carried on arches of thick bundled stems planted in two rows and bent together (ArCHIAM, 2025). The principle is efficient and directly relevant, bundled reed acts in compression, spans as an arch, and is light. For at least five thousand years the mudhif has shown that reed alone can make primary structure (Shepperson, 2026).

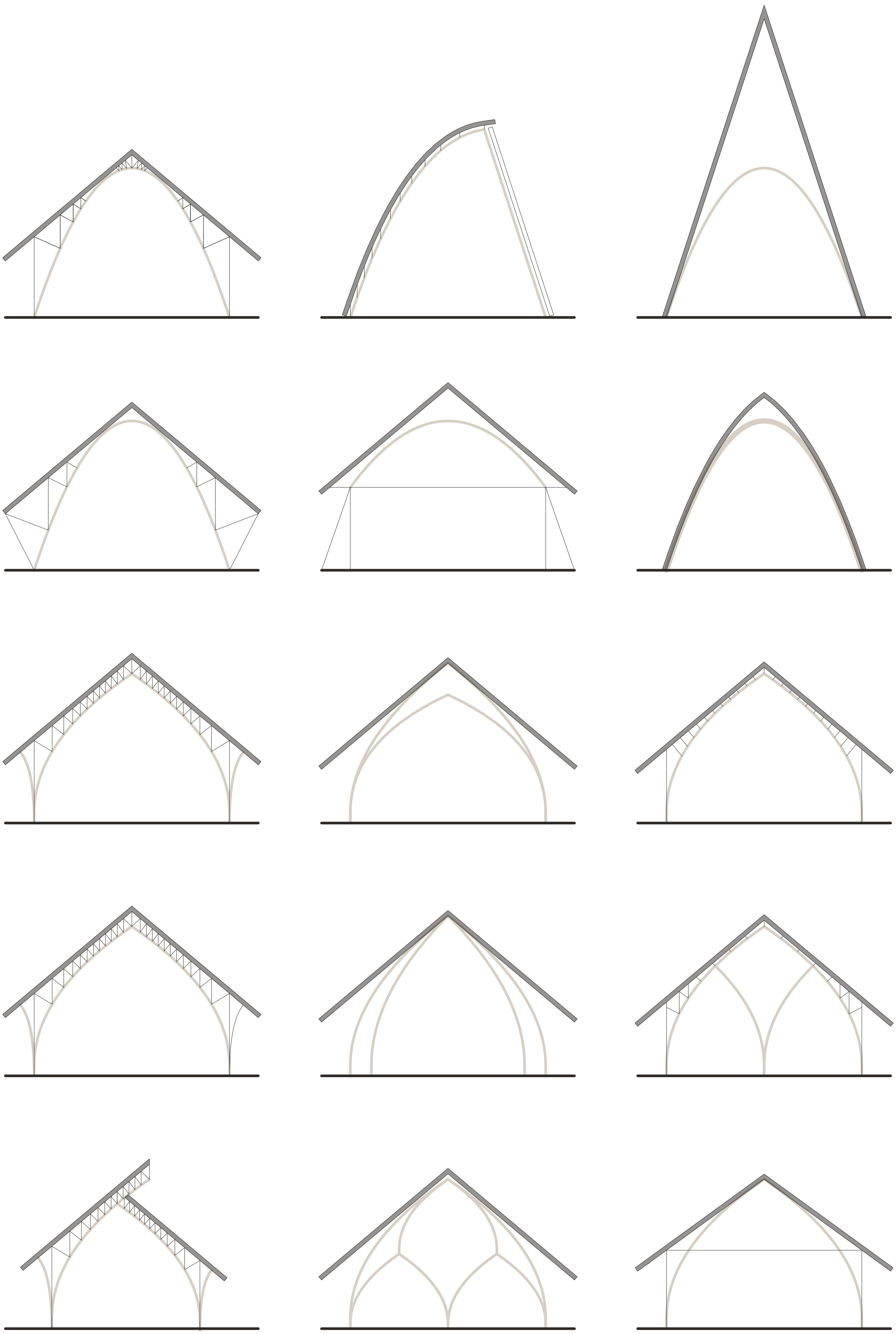
It also shows the limits. Reed bundles cap the achievable span, which is why traditional mudhifs stay long and narrow, and why, in practice, modern builders in the marshes began inserting welded steel frames after 2010 to break that constraint (Shepperson, 2026). This project makes the same hybrid move deliberately: reed arches do the spanning, steel does the connecting.

Two constraints shaped the geometry. The span limit of bundled reed pushes the plan long and single-storey; nothing above a ground floor is feasible. And the roof is thatch, which needs a pitch of at least 40° to shed water and decay slowly, shallower roofs rot faster (Malheiro et al., 2021). The arch therefore has to meet a steep roof. Early parabolic profiles gave clean compression but sat awkwardly under the ridge, so the studies moved toward a more pointed, gothic profile: it keeps the arch largely in compression, drives load downward rather than outward, and aligns with the roof's apex.

*Fig. 35: Physical model to explore arch-roof connections*

Where the mudhif binds its bundles with reed rope, that binding point becomes an opportunity. The connection is where the roof beams need support and where the façade-protecting overhang springs. The steel connectors shown in the physical model resolve that junction, clamping the bundle, receiving the roof trusses, and carrying the overhang in one detail.

*Fig. 36: construction iterations*



# Experimental tectonics: ventilated reed reed facade

Reed already solves the inner layers of a wall. Loose reed insulates, and reed-clay infill adds thermal mass and buffers moisture, both established and effective (Malheiro et al., 2021). What the reed palette lacks is a finish: an outer panel that presents the material to the public and protects what sits behind it.

That gap is the experiment. Shredded reed fibre was cold-pressed with a range of bio-binders to test panels for façade use. The matrix opposite crosses three fibre sizes against five binders. The final choice became a combination of  Tannin and bio-epoxy, for a combination of strength and visuals. The aim was a panel that is reed-based, structurally adequate as cladding, and free of fossil adhesives (See figure 40).

The difficulty is rot. A pressed-reed panel is biological and will degrade outdoors (Malheiro et al., 2021). Rather than fight this, the design accepts it. The roof overhang, springing from the arch connection, keeps the worst of the rain off. More importantly, the wetland produces new reed every winter, so a degraded panel is not a failure but a replaceable unit, the same logic that lets a thatched roof be re-laid in sections. To make replacement real, panels are sized to a standard 1200 × 1200 mm, so they are interchangeable, manufacturable in series, and usable beyond this one building.

The detail is therefore a ventilated panel façade: a drained, back-ventilated cavity keeps the visible reed layer as dry as possible while still showing the material openly. Dry reed lasts longer; exposed reed communicates the system. The two goal, durability and legibility, are reconciled by the cavity.

This reframes the building itself. Because pressed panels are simply reed, binder and a mould, the visitor centre is also a small production site for them: the wetland grows the fibre, the building presses the panels, and the moulds can be changed to make whatever shape is needed, including the forms studied next.

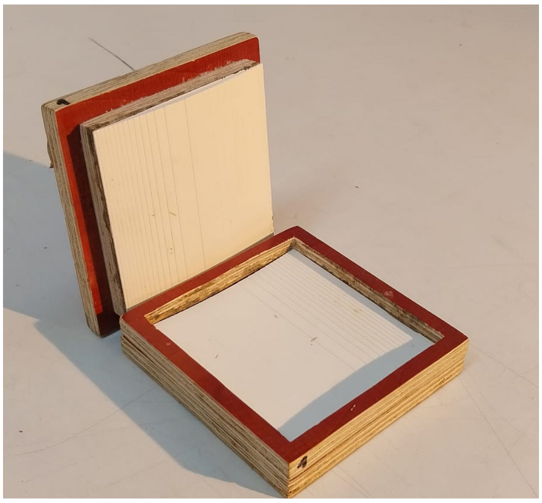


*Fig. 37: Cold press with 3D prited mold*

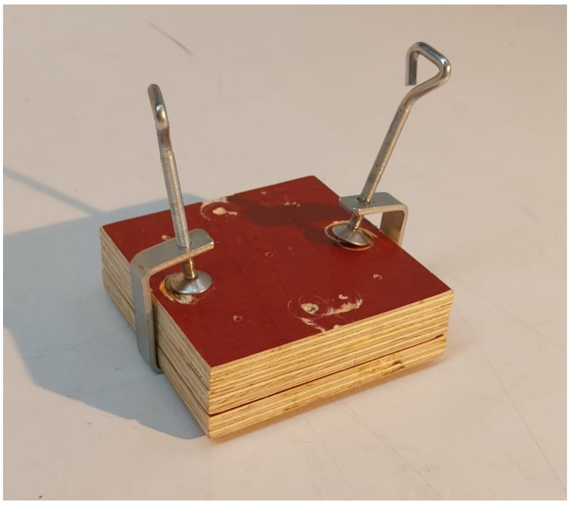
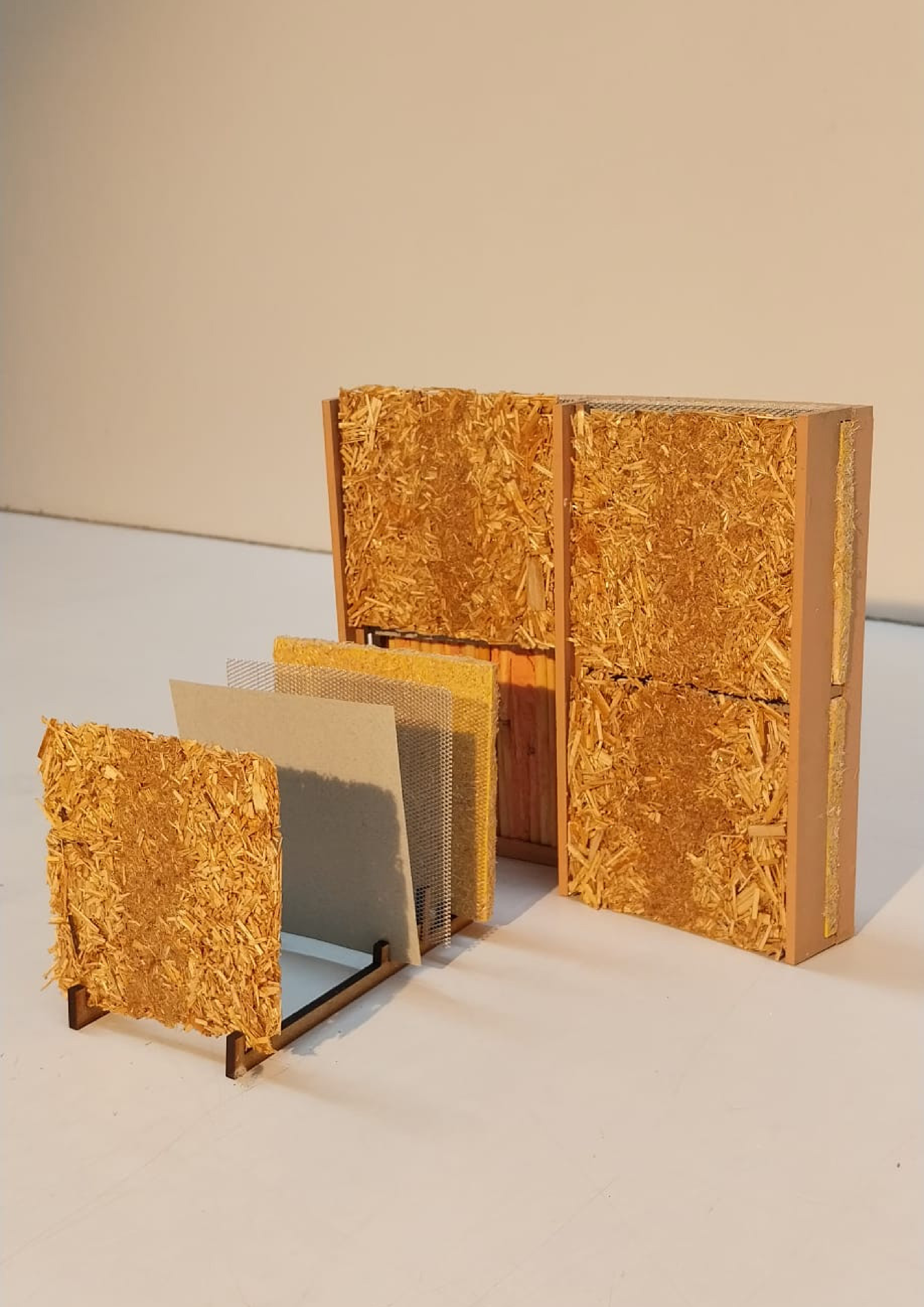


*Fig. 38: Closed cold press*

*Fig. 39: Facade buildup model*



Starch binder
*8 g starch - 80 ml Water*
50 mm fibers
*15 g*

Starch binder
*8 g starch - 80 ml Water*
15 mm fibers
*15 g*

Starch binder
*8 g starch - 80 ml Water*
5 mm fibers
*15 g*

## Starch binder: light, semi-brittle, uneven bonding

*Source: Plant-based polysaccharide (corn, potato, wheat).*
*Mechanism: Hydrogen bonding when water evaporates.*
*Behaviour: Low viscosity, penetrates well but limited cross-linking.*
*Moisture: Sensitive to prolonged humidity.*
*Fire: Combustible, no inherent fire resistance.*
*Liu, M. et al. (2015) Starch-based adhesives: structure and performance.*

*During pressing, a large amount of binder was squeezed out, showing low viscosity and internal cohesion under pressure. The panels are relatively light and the binder visually translucent, as it dries clear. The material is moderately strong but irregular. The 50 mm fibers show loose zones and weak cohesion, likely due to insufficient penetration and mechanical interlocking. Shorter fibers (5 mm) result in smoother surfaces and better binder distribution, indicating that starch performs better with finer fiber matrixes. Overall, the composite is quite brittle and sensitive to local inconsistencies in fiber density.*

Soy protein binder
*5 g soy - 12 ml water - 0,4 g lime*
50 mm fibers
*15 g*

Soy protein binder
*5 g soy - 12 ml water - 0,4 g lime*
15 mm fibers
*15 g*

Soy protein binder
*5 g soy - 12 ml water - 0,4 g lime*
5 mm fibers
*15 g*

## Soy protein binder: strong and well distributed

*Source: Plant protein (soy flour).*
*Mechanism: Protein denaturation + cross-linking during curing.*
*Behaviour: Strong, slightly more flexible than starch.*
*Moisture: High sensitivity unless modified.*
*Fire: Organic – combustible, but can char.*
*Protein-based adhesives: bonding mechanisms of casein adhesives, Haddad, J. et al. (2013)*

*Panels show high strength and good internal cohesion. The binder remains visually transparent and allows the reed texture to remain visible. Fiber bonding appears more homogeneous than starch or casein, with fewer loose zones. The composite feels compact and mechanically stable across all fiber lengths. The binder shows consistent performance across fiber variations.*

Caseïn binder
*6 g casein - 18 ml water - 0,8 g lime*
50 mm fibers
*15 g*

Caseïn binder
*6 g casein - 18 ml water - 0,8 g lime*
15 mm fibers
*15 g*

Caseïn binder
*6 g casein - 18 ml water - 0,8 g lime*
5 mm fibers
*15 g*

## Caseïn binder :strong but unevenly distributed

*Source: Milk protein.*
*Mechanism: Lime activates casein into calcium caseinate, creating strong mineral-protein bonds.*
*Behaviour: High strength, rigid matrix.*
*Moisture: Moderate water resistance after curing.*
*Fire: Slightly improved performance due to mineral (lime) content.*
*Du, G. et al. (2017) Soy protein adhesives: modification and bonding performance. Journal of Industrial Crops and Products.*

*The tests show high overall strength and medium weight. The initial white chocolate smell disappeared after curing. A slight yellow tint is visible. Although structurally strong, binder distribution appears inconsistent, particularly in longer fibers. Some areas feel under-bonded, suggesting that either higher binder content or improved mixing may be required. The composite feels dense and rigid, with good cohesion but a lot of room for optimization in homogeneity.*

**Tannin binder** — **50 mm fibers**
*6 g starch - 16 ml Water - 0,7 g lime* — *15 g*

**Tannin binder** — **15 mm fibers**
*6 g starch - 16 ml Water - 0,7 g lime* — *15 g*

**Tannin binder** — **5 mm fibers**
*6 g starch - 16 ml Water - 0,7 g lime* — *15 g*

## Tannin binder: visible but brittle

*Source: Tree bark extract (polyphenols).*
*Mechanism: Phenolic-type cross-linking reactions.*
*Behaviour: Rigid and brittle matrix without plasticizers.*
*Moisture: Good resistance once cured.*
*Fire: Better charring behaviour due to phenolic structure.*
*Tannin adhesives: A century of development, Pizzi, A. (2019)(2013)*

*The panels are extremely brittle. The 50 mm sample fractured completely, while 15 mm and 5 mm samples show chipped edges and corner failure. Black spotting is visible, likely from lime reaction. The panels have a darker brown coloration and slightly glossy, reflective surface. The material feels rigid but fragile, suggesting strong but inflexible cross-linking behaviour.*

**(Bio) Epoxy binder** — **50 mm fibers**
*3 g epoxy resin - 5 g hardener* — *15 g*

**(Bio) Epoxy binder** — **15 mm fibers**
*3 g epoxy resin - 5 g hardener* — *15 g*

**(Bio) Epoxy binder** — **5 mm fibers**
*3 g epoxy resin - 5 g hardener* — *15 g*

## (Bio)epoxy: highest strength, non-reversible

*Source: Partially plant-based thermoset resin.*
*Mechanism: Chemical cross-linking polymerization (irreversible).*
*Behaviour: Highest mechanical strength.*
*Moisture: Good resistance.*
*Fire: Depends on formulation; combustible but structurally stable.*
*Grau, E. et al. (2016) Bio-based epoxy resins: synthesis and applications. Polymer Chemistry.*

*Panels are highly cohesive and visually transparent. Mechanical strength is the highest among all tested binders. The natural reed smell disappears completely and is replaced by a noticeable chemical odor during curing. The composite is dense, strong, and structurally reliable, but lacks the material reversibility of the bio-based binders.*

*Fig. 40: Cold pressed reed fiber panel matrix*

# Experimental tectonics - Form studies

The panel face is not decoration; it carries four jobs at once. It must shed water, so its dominant lines run vertical, channelling rain downward off the reed. It must belong to its landscape, so the geometry abstracts the movement of reed fields along the Dommel, stems and wind-driven waves, the wetland legible in the wall. It must allow dry assembly, so each panel's edges register precisely against its neighbours without sealant. And it should reward looking, so convex and concave surfaces shift the reading of the façade between near and far, a depth effect across the elevation.

These were developed parametrically. A Grasshopper script generated and varied the geometry against these criteria, and selected panels were 3D-printed to test them physically. The curvature does double duty: convex and concave surfaces manage runoff and stiffen the compressed reed-fibre composite, so the form that abstracts the reedbed also strengthens the panel.

The result ties the façade back to the project's circular logic. Panels are mechanically fixed, fully removable, and reed-based throughout, so they can be maintained, swapped, and at end of life returned to the material cycle rather than discarded. Form, water management, structure and circularity are resolved in a single geometry.

*Fig. 41: 3D printed facade shapes*

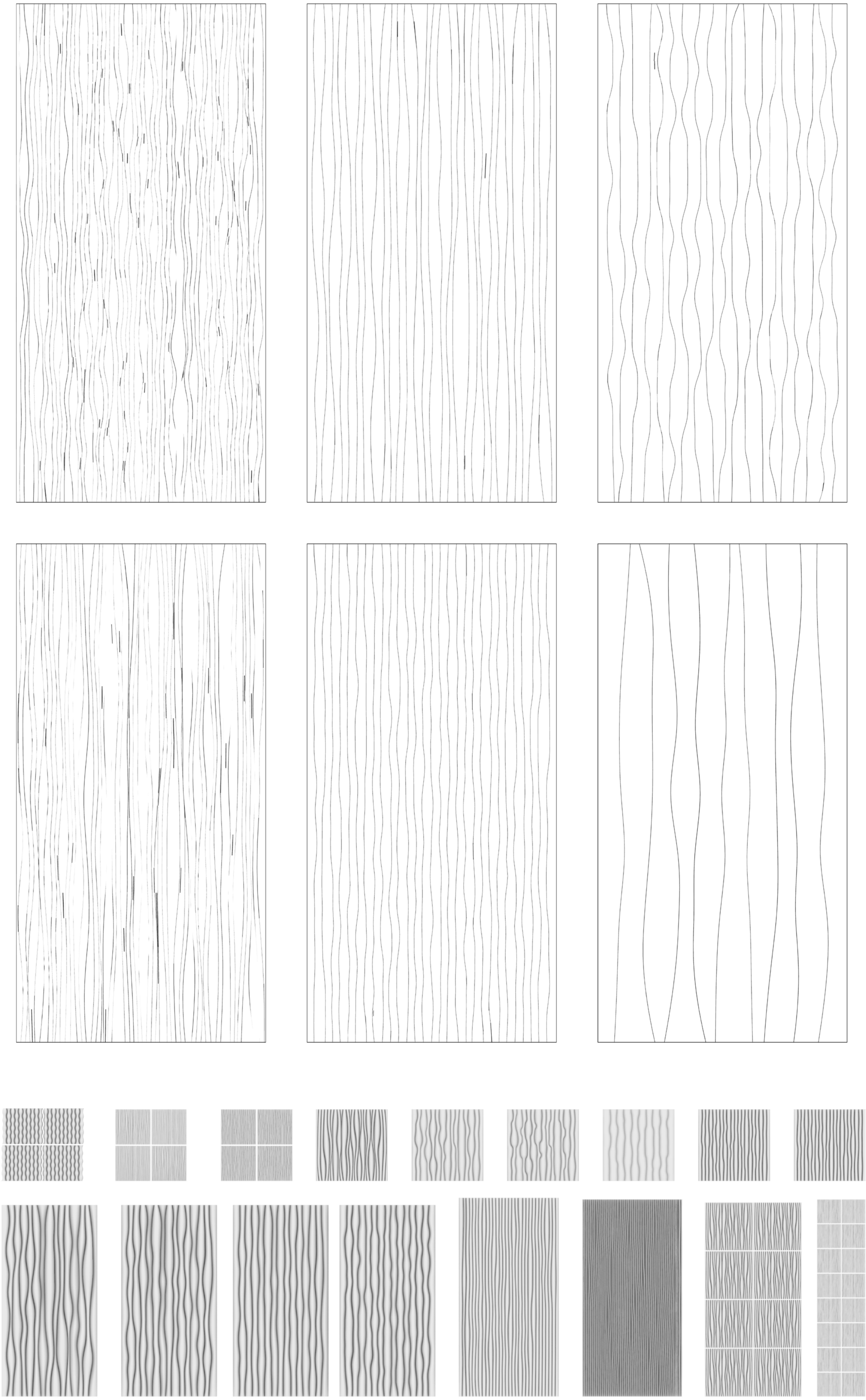


*Fig. 42: facade shape iterations*

***Thatched roof***
*Thatch of whole reed stems, pitched above 40° to shed water and decay slowly with overhangs that shelter the façade below.*

***Bundled reed portal structure***
*Mudhif-derived arches of bundled reed acting in compression, spanning the long single-storey plan, with steel connectors at the binding points carrying roof and overhang*

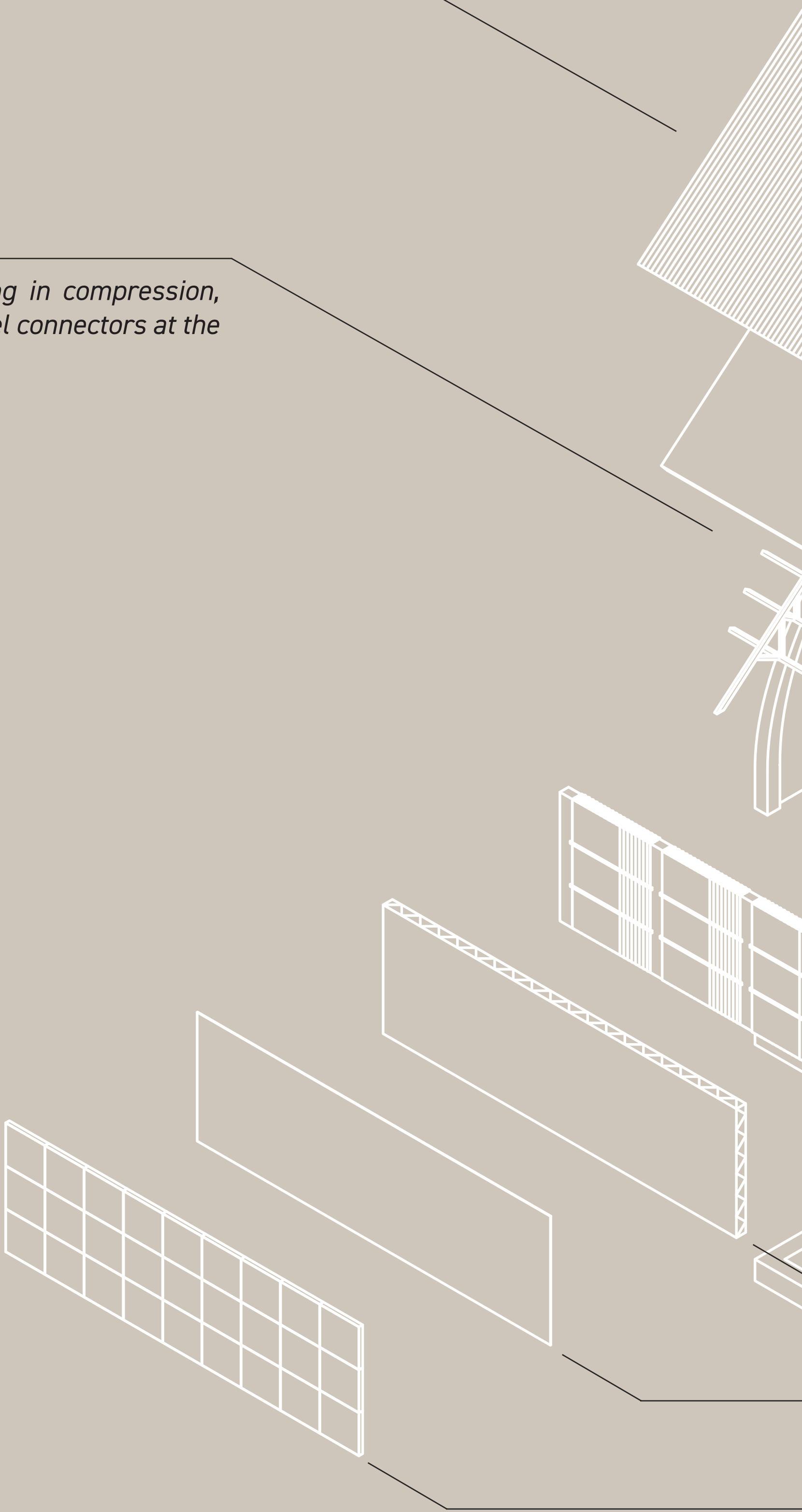
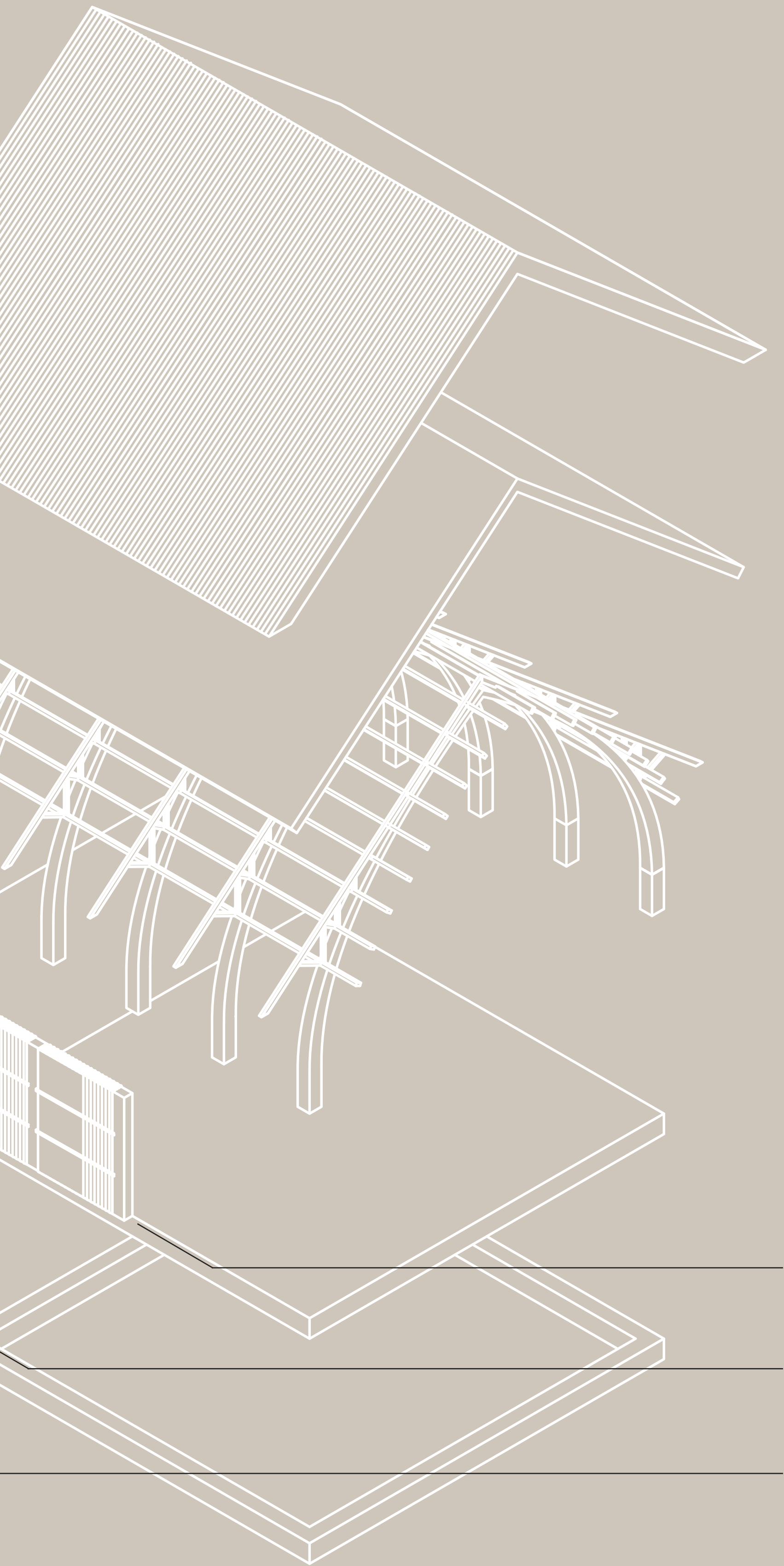


*Fig. 43: New building layers*



***Infillll***
 *Reed-clay thermal mass and moisture buffering on the warm side*

***Insulation***
*Loose reed fibre traps air; ~0.06–0.08 W/m·K, comparable to bio-based insulation.*

***Cavity & water resistant layer***
*Drained, back-ventilated space keeping the visible reed dry; reconciles durability with exposure*

***Cladding***
*Pressed reed-fibre panels (ventilated) Standardised 1200×1200 mm, mechanically fixed and fully removable; shows the material while being replaceable as it weathers.*

# Typological positioning

The building has an unusual job: it is two building types at once. It is a visitor centre, public, educational, a place to understand nitrogen, wetlands, and the lost stream-valley ecology. And it is a production facility, where reed is harvested, processed, and pressed into the panels the building itself wears.

The thesis is that these should not be separate. The production is the lesson. The model is something like a working winery, where the press and the cellar are part of the visit rather than hidden behind it. Here the visitor arrives in a constructed wetland, sees the reed being grown and cut, learns why a nutrient-poor landscape is worth restoring, watches the material being made, and then makes something themselves in a workshop. Understanding moves from the abstract problem (nitrogen, deposition, biodiversity loss) to its embodied answer (a panel, a bundle, a thatch) to the visitor's own hands.

Three conditions follow from this and shape everything downstream. The building stands in the wetland, not beside it, so the system is the setting. It is single-storey, set by the reed structure's span limit. And it is openly temporary: thatch, arches, and panels are all reed, all biodegradable, all on a replacement cycle fed by the annual harvest. The building is not built once and maintained, it is continually remade from the landscape it sits in. That is the type: a production-visitor centre that demonstrates its own material cycle by living inside it.

# Programmatic framework

The project converts an unsused asphalt site into a productive, climate-adaptive landscape that holds water, builds biodiversity, grows bio-based material, supports research, and engages the public. Architecture and landscape are not designed as object and setting but as one system.

The intervention covers roughly 4,000 m² of landscape with 800-900 m² of built floor area, organised as a clear gradient from the urban edge to the river. The building sits on raised ground for flood safety and overlook, opening to the northwest across the water and presenting a closed face toward the infrastructure behind it. To the northeast the ground is lowered into a wetland connected to the Dommel floodplain — a helophyte filter, seasonal storage, and harvestable reed fields. Boardwalks carry the public across without disturbing the sensitive ecological zones.

The building (≈ 800-900 m²) contains:
- entrance and reception (≈ 60 m²);
- exhibition space (≈ 150 m²);
- Production space (≈ 250 m²)
- workshop / maker space (≈ 80 m²);
- café / lecture room (≈ 100–150 m²);
- office and storage (≈ 100 m²).

The landscape contains: an enlarged water-storage area; a constructed wetland filter of at least 2000 m²; reed cultivation for material production; zones of varying water depth for habitat range; a partially inaccessible ecological core; and elevated walking routes.

These are not five functions in a building and several features in a park; they are one loop laid out in space. The exhibition explains the wetland the visitor is standing in; the workshop uses the reed the fields produce; the café overlooks the water the filter cleans. The programme is the material cycle made walkable.

The design must, accordingly: contribute to water buffering and climate adaptation; enhance biodiversity; demonstrate a circular material cycle; remain publicly accessible and educational; and integrally connect architecture and landscape. These five requirements are the test every subsequent design decision is measured against, and they map directly onto the five criteria used to select the landscape strategies in Chapter 3, closing the line from problem to programme.

# Architectural precident: Tåkern

Tåkern Visitor Centre (Naturum Tåkern, Wingårdh Arkitektkontor, Lake Tåkern, Sweden, 2012) is a reed-clad visitor centre on a wetland, where both walls and roof are thatched and the steep pitch is used to extend the thatch's life (Wingårdh, 2012). Two moves matter for this project. First, the ridge, the most vulnerable point of any thatched roof, is replaced by a glazed skylight, turning thatch's structural weak point into a daylight source. Second, the building's reasoning mirrors this thesis directly: it lays reed at a steep pitch precisely because, at 45° or less, water runs off and the roof lasts 50–70 years (Swedish Wood, 2012), the same pitch logic driving this design's roof and arch geometry. Tåkern proves the glazed-ridge detail and the steep-thatch principle in a built, wetland-sited visitor centre. (Trä Magazins, z.d.)

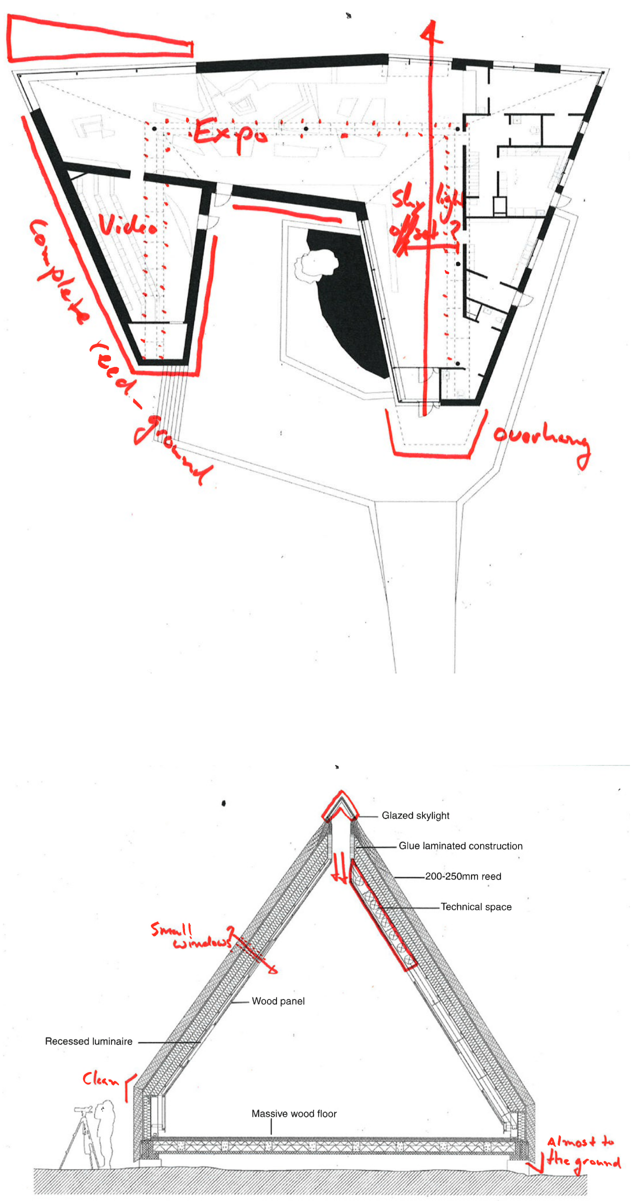


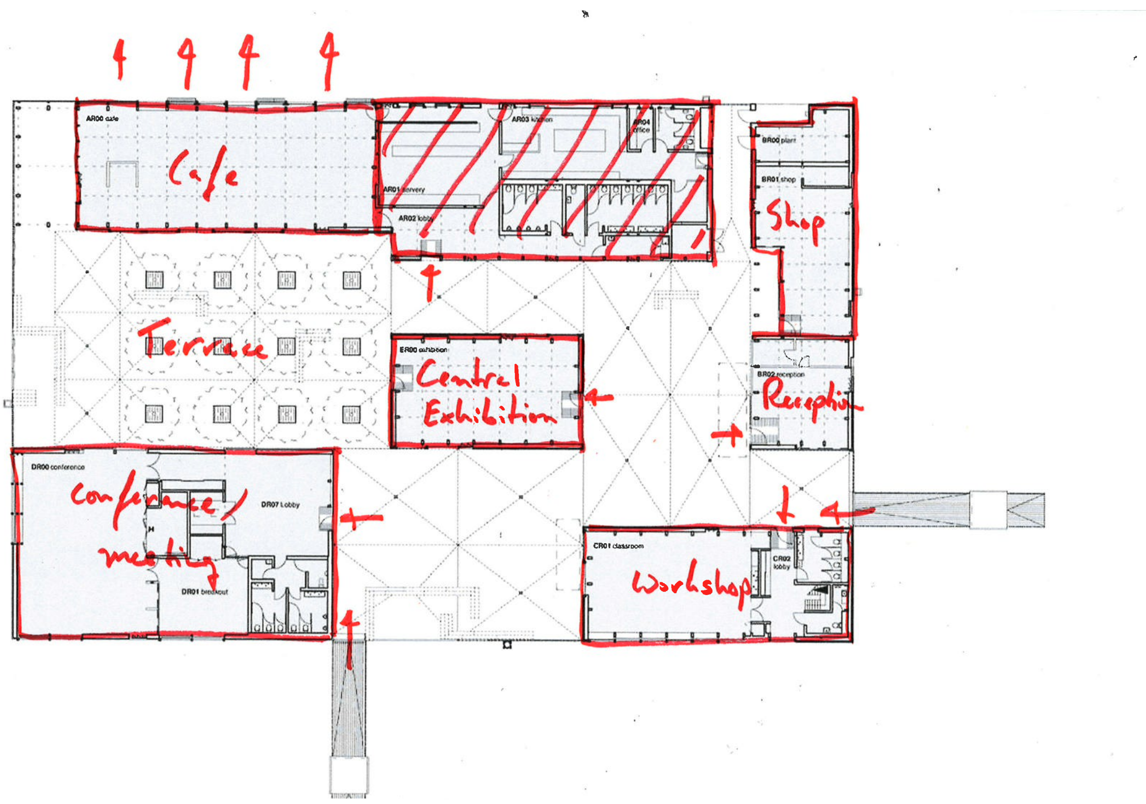

*Fig. 44/45: Analysis of Tåkern (based on Archdaily, z.d.)*

*Fig. 46: Entrance of Tåkern (archdaily, z.d.)*


naturum

# Architectural precident : Brockholes

Brockholes Visitor Centre (Adam Khan Architects, 2011) is a nature-reserve centre that breaks a large programme into a village-like cluster of barn-roofed volumes, each function legible as its own building. Its clarity of functional division is the reference for organising this project's mixed exhibition, workshop, and café programme. Notably, Brockholes itself drew on the Marsh Arab reed villages of the Tigris-Euphrates (Price & Myers, n.d.), the same mudhif tradition behind this project's structure, making the two precedents part of one lineage.



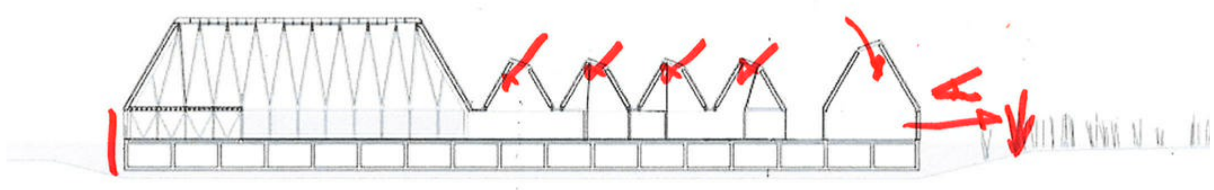
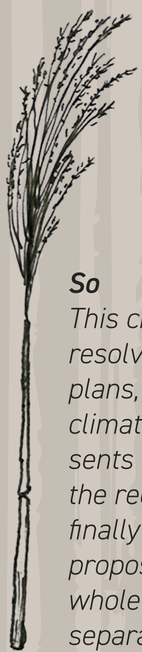



*Fig. 47: View on Brockoles (Adamkhan, z.d.)*

*Fig. 48/49: Analysis of Brockoles (based on Adamkhan, z.d.)*



***So***

*This chapter shows the resolved design. Through plans, sections, structure, climate, and detail, it presents how the wetland, the reed, and the building finally come together the proposal as a coherent whole rather than a set of separate decisions.*

# Results

Architectural Masterplan

*Massing*

*Programme*

*Floorplans*

*Sections*

Structure

Climate

Detailing


1
2
3
4
5

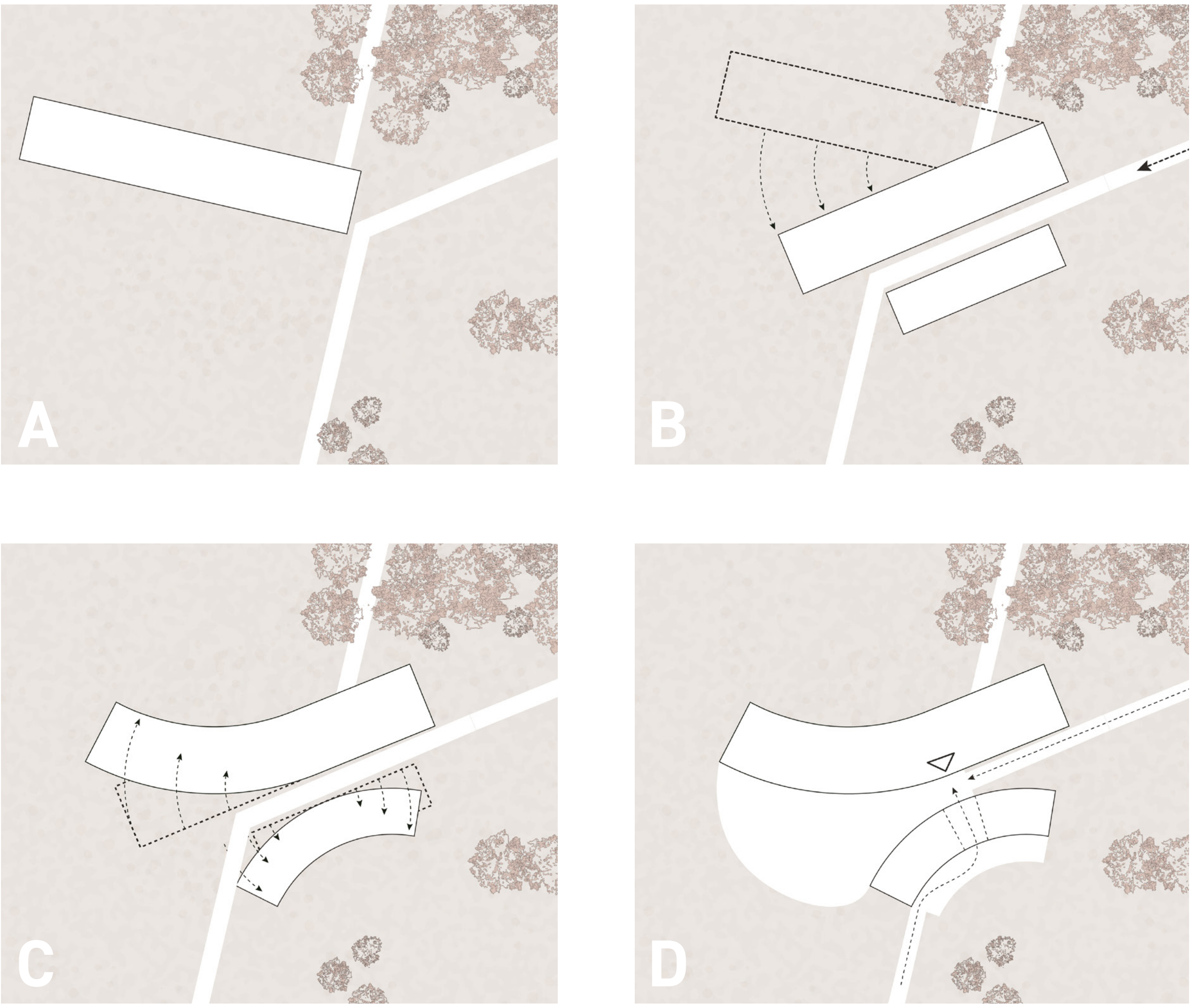



*Fig. 51: Massing*

# Massing

The plot is empty, which leaves the placement open. Options close to the Dommel (1 and 2) sit well by the water but fall far from the existing paths and the new VONK park. Option 4 crowds the residents to the south and the point where water enters the plot, where the sedimentation basin needs to go. Option 5 is central but splits the plot in two, and the wetland should read as one continuous system. Option 3 resolves all of this: central, connected to the new pedestrian route to VONK park, with the road to the north available as a separate service and material route, keeping logistics clear of visitors.

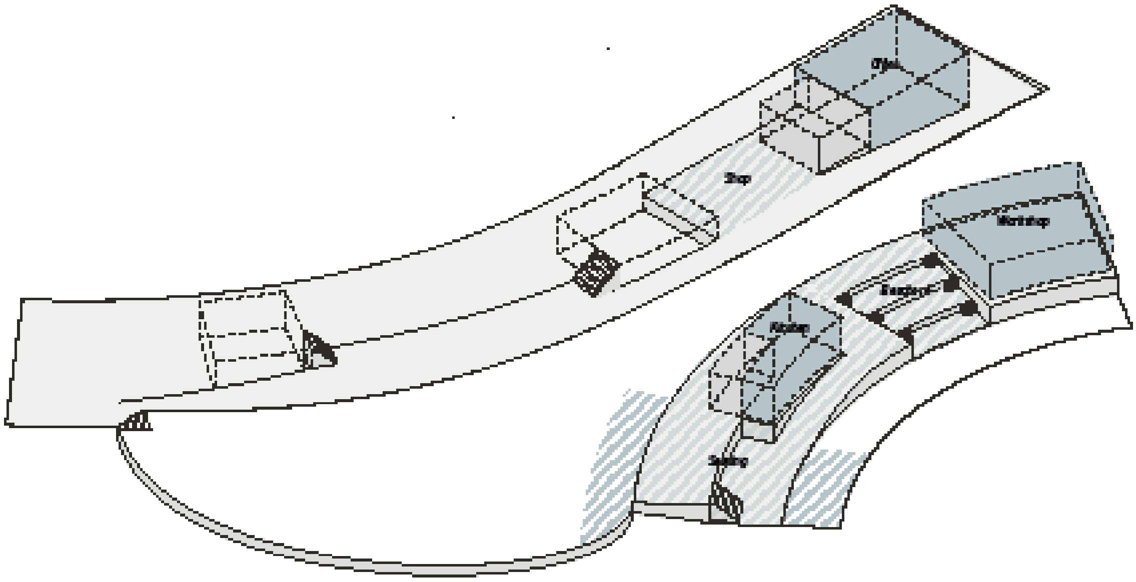
The programme's floor area is first set out as a single long, narrow mass, the reed arches cannot span wide, so length is the only way to grow (A). That mass is then rotated parallel to the entrance road, lengthening visitors' contact with the reed façade as they approach, and split into two volumes: production and exhibition above, café and workshop below, so the two public modes, watching the material being made, and using it yourself, each get their own building (B).Then the straight volumes are bent toward the landscape, opening sightlines across the reedfields, exploiting the sculptability of a thatched roof, and staging a moment of release as visitors pass between the two masses (C). A terrace emerges in the gap, and the southern path runs on through the upper mass, placing the entrance in its middle, so visitors first meet the material in the façade, then step inside to its explanation. (D)

*Fig. 50: Location options*

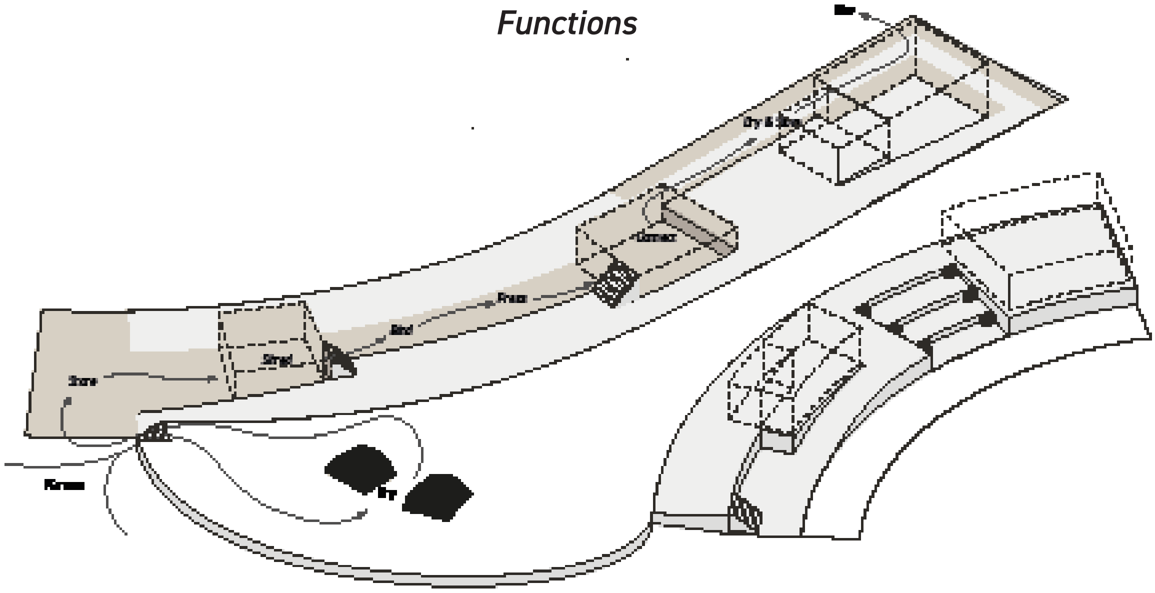
# Programme

Soil dug from the wetland raises a plateau, with the terrace on top and the masses carved into it, so visitors look out over the reed rather than against it, and the level changes generate half-levels for voids, stairs, and viewing platforms. The entrance opens onto shop, toilets, and office, the latter set against the service road for staff access. The whole northwest holds the production line on the ground floor: a direct run from wetland to service road. The exhibition overlooks this process, curving around it and returning past the far side. The layout borrows from the factory hall, the reed arches define two large halls, within which the functions that need it sit as boxes-within-a-box: the loud shredding and connecting steps, the café kitchen, the office, and the toilets. Exhibition platforms float above the production rooms. The sequence is deliberate: approaching the two buildings, visitors first glimpse the stored panels and a workshop in progress through the windows left and right, then walk along the reed-panel walls themselves.

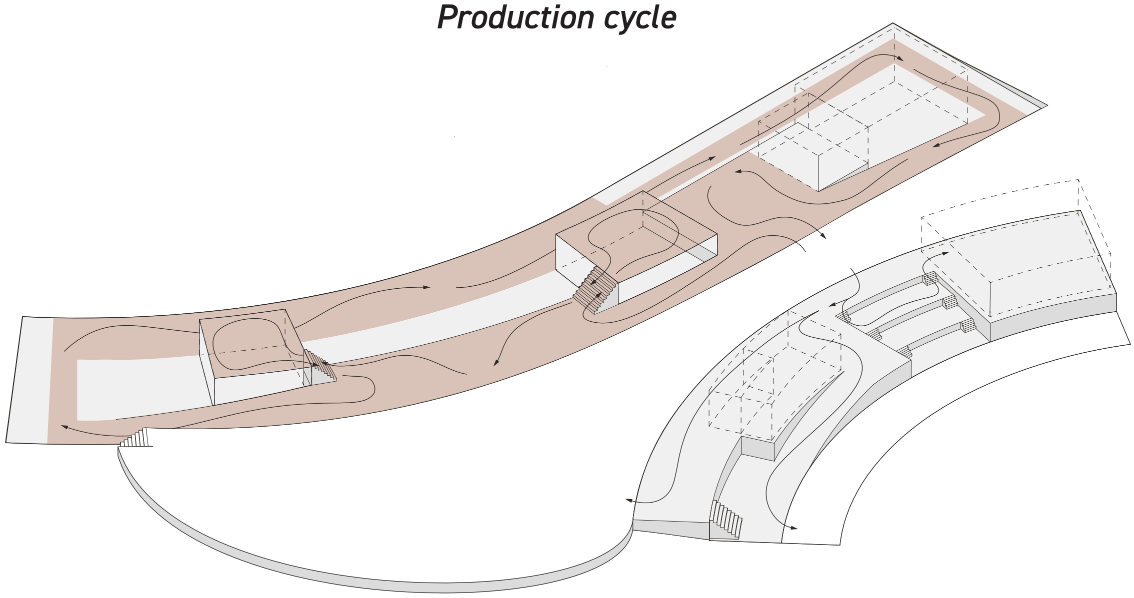
*Fig. 52: Programme*



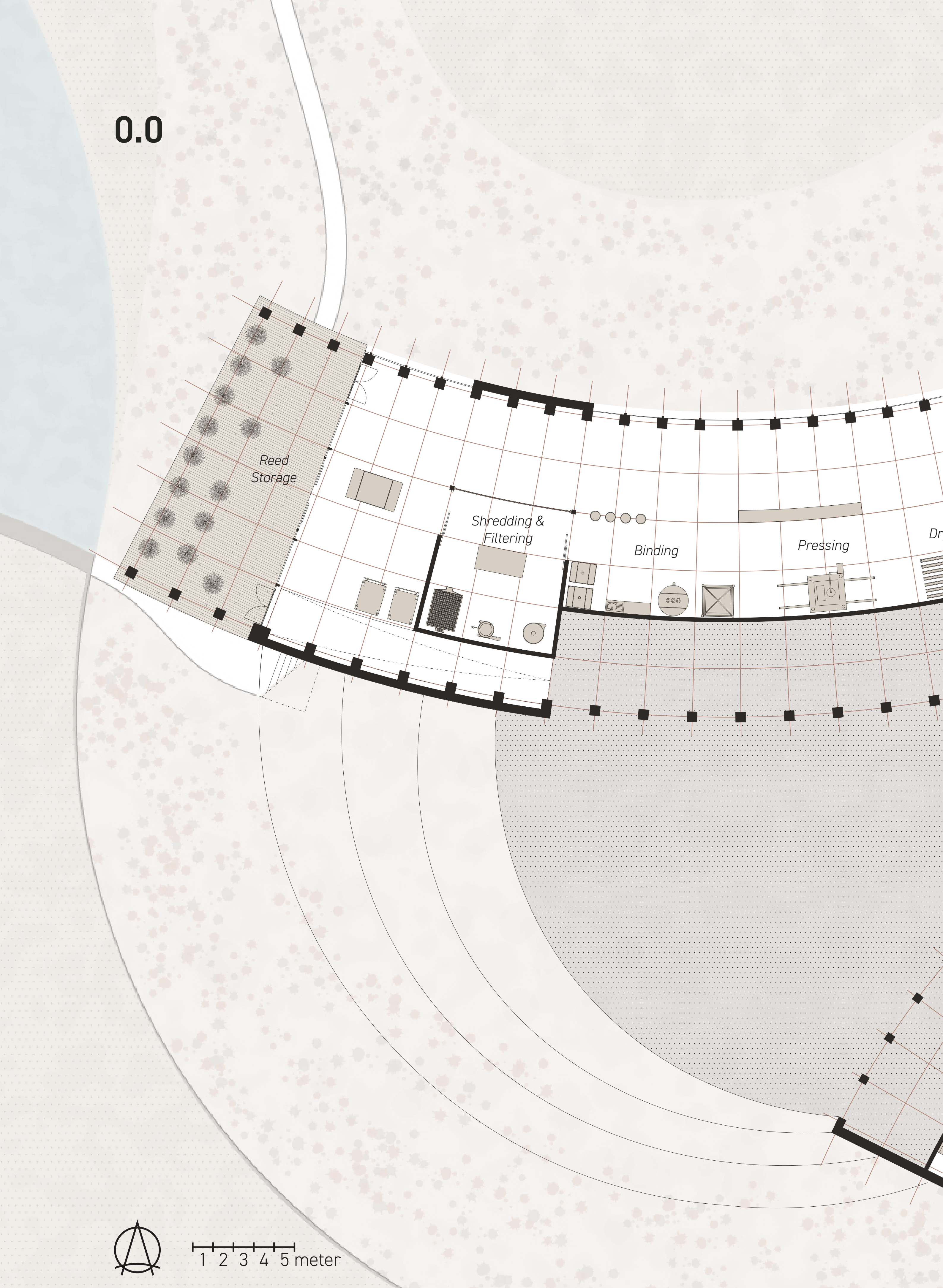

*Functions*

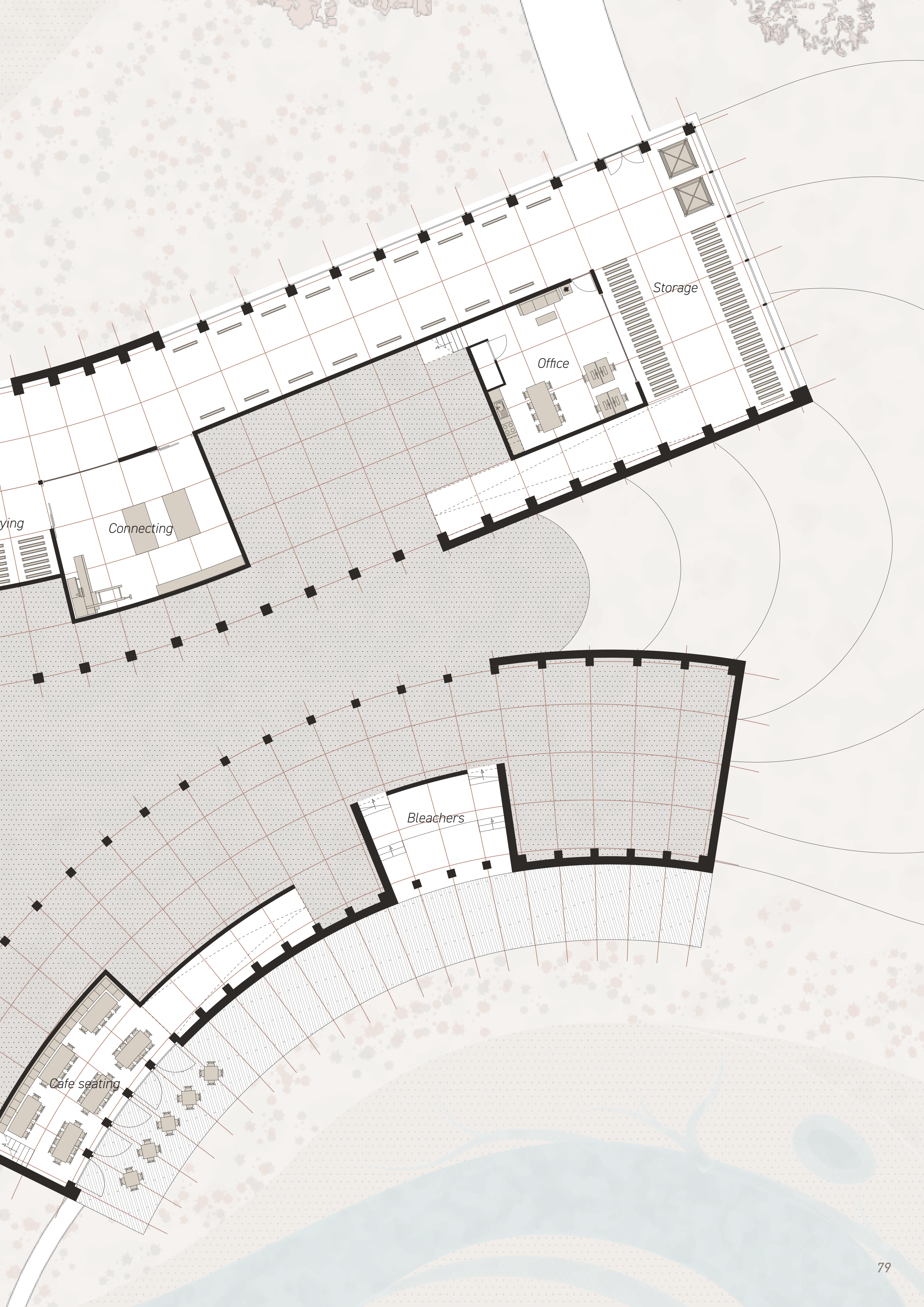


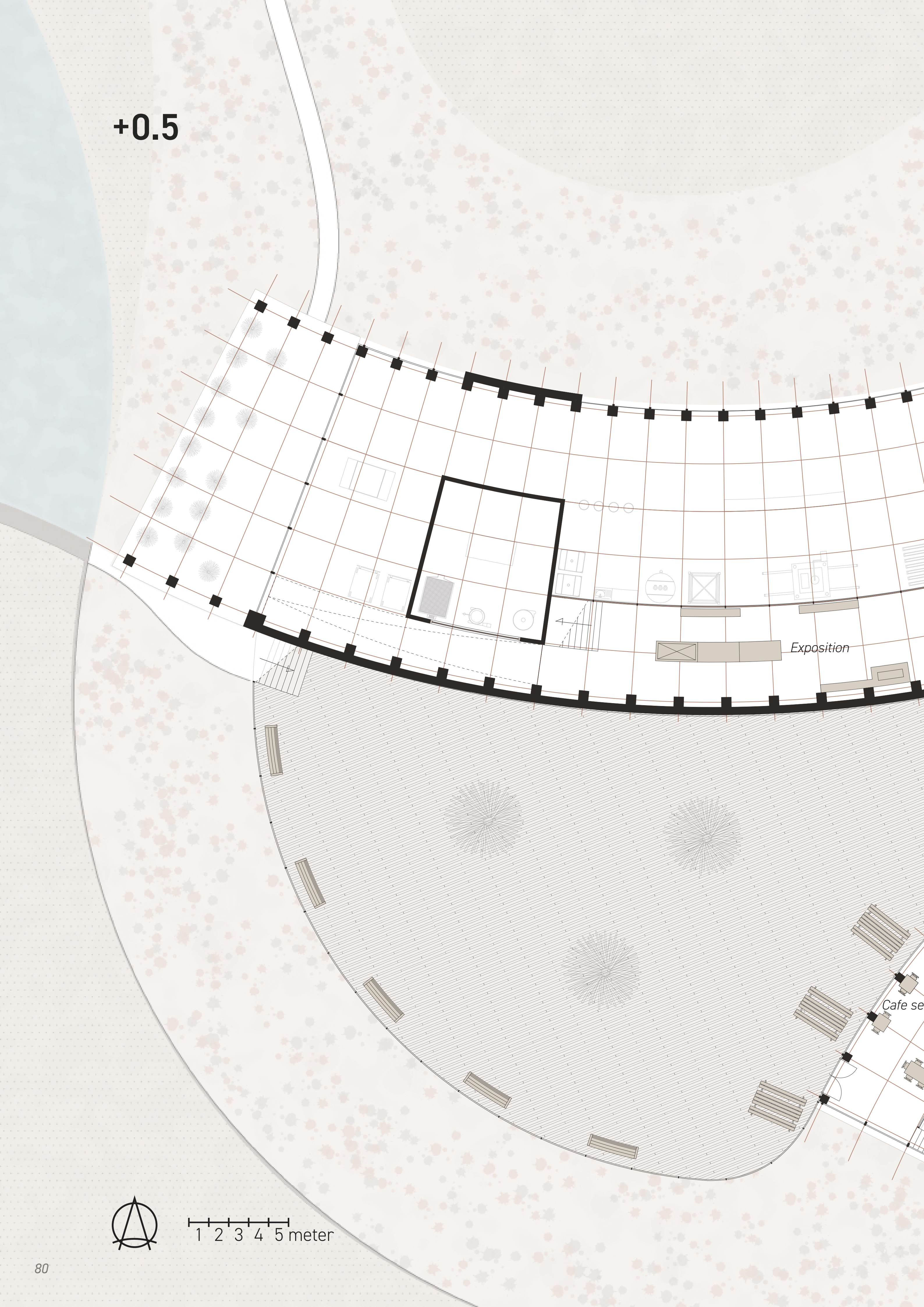

*Production cycle*



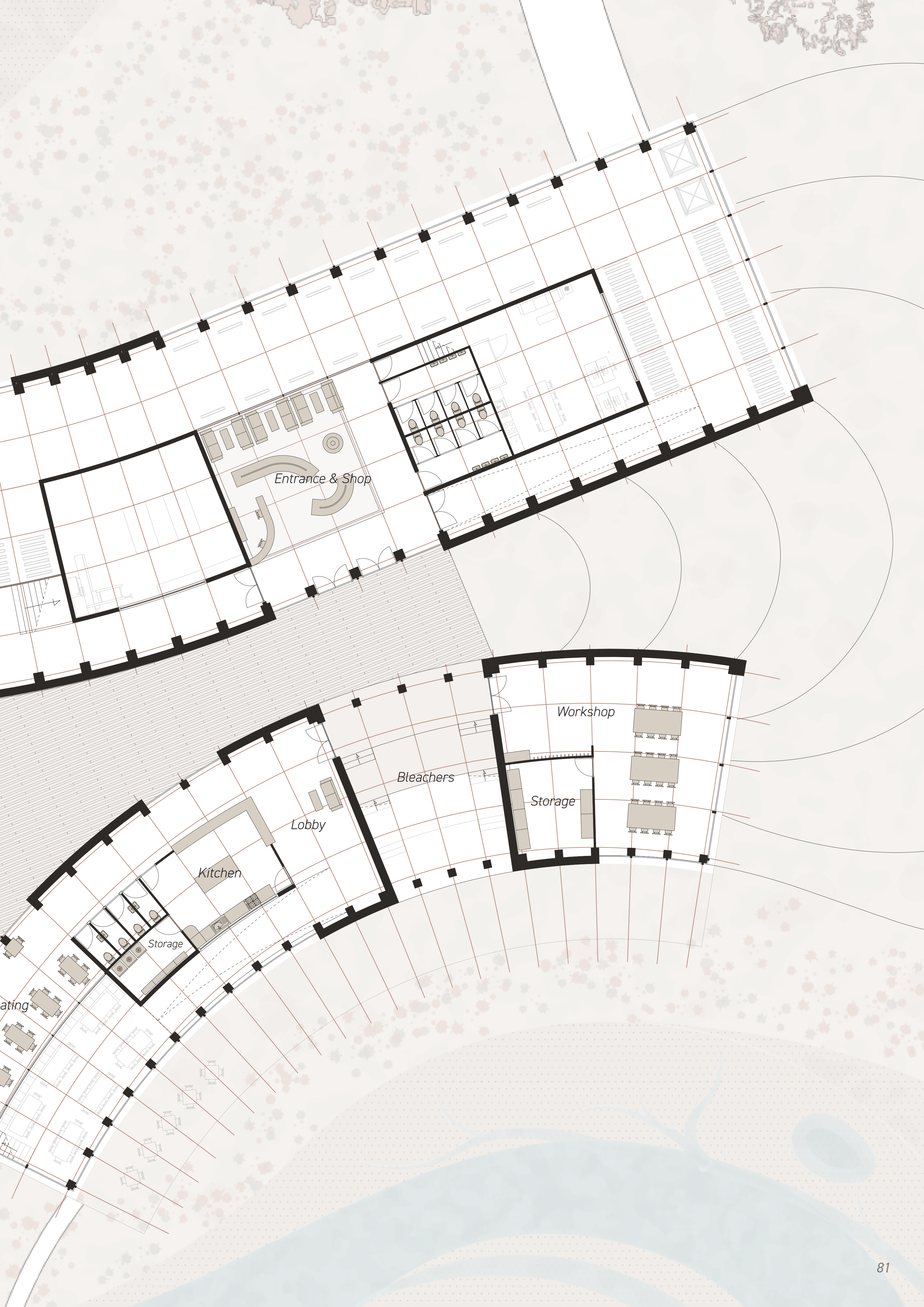
*Visitor routing*

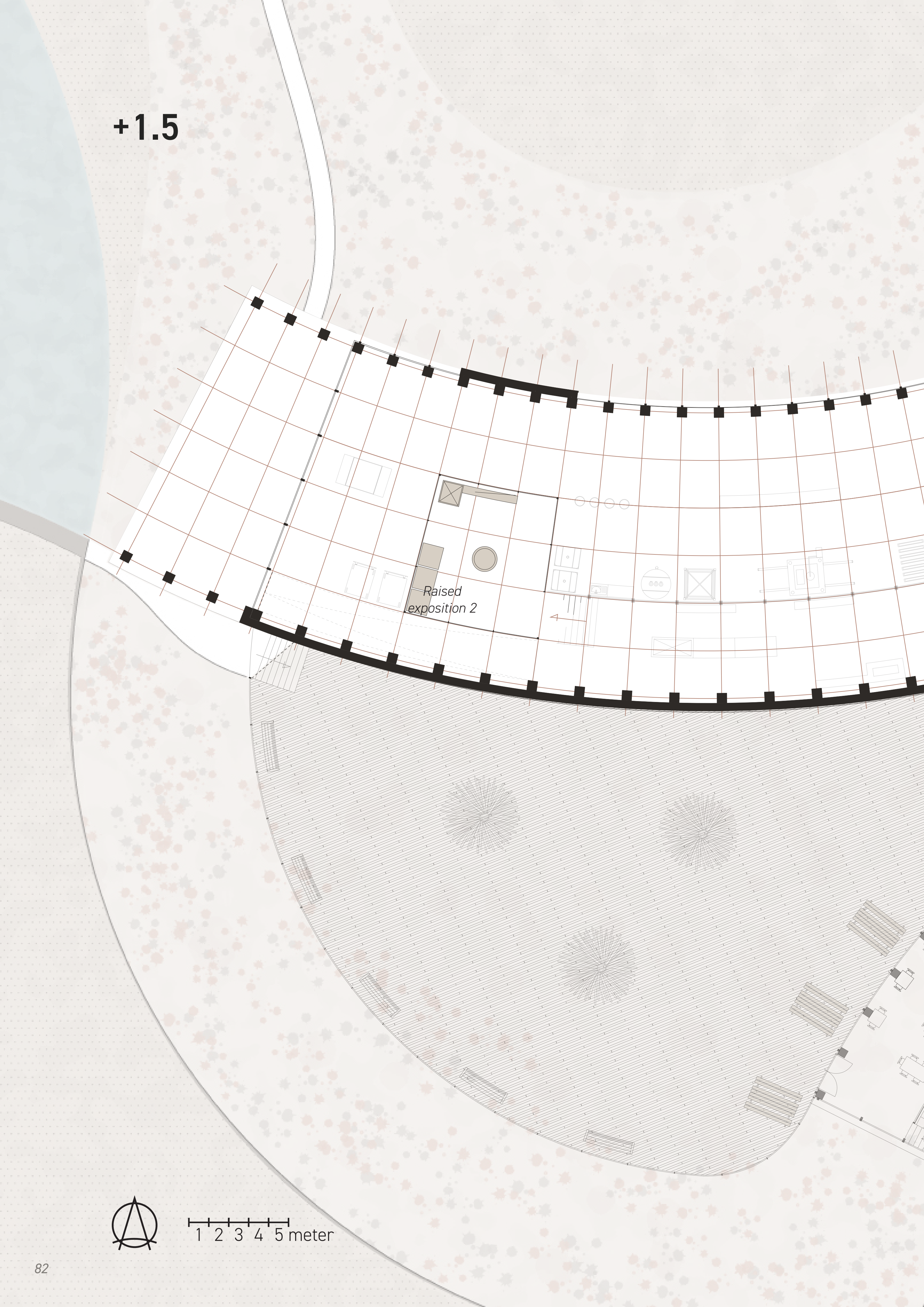

0.0
Reed Storage
Shredding & Filtering
Binding
Pressing
1 2 3 4 5 meter

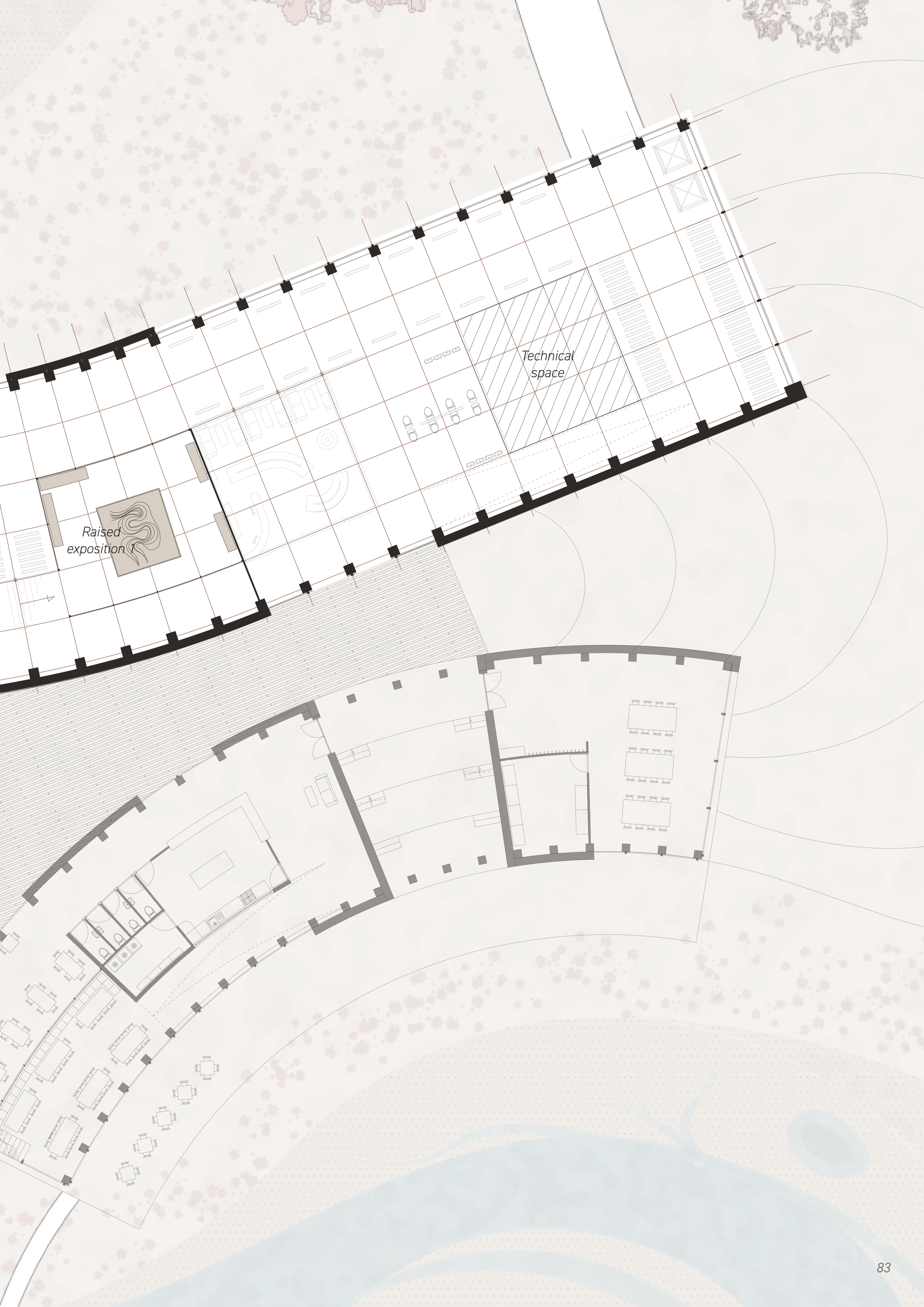

Storage
Office
Connecting
ying
Bleachers
Cafe seating

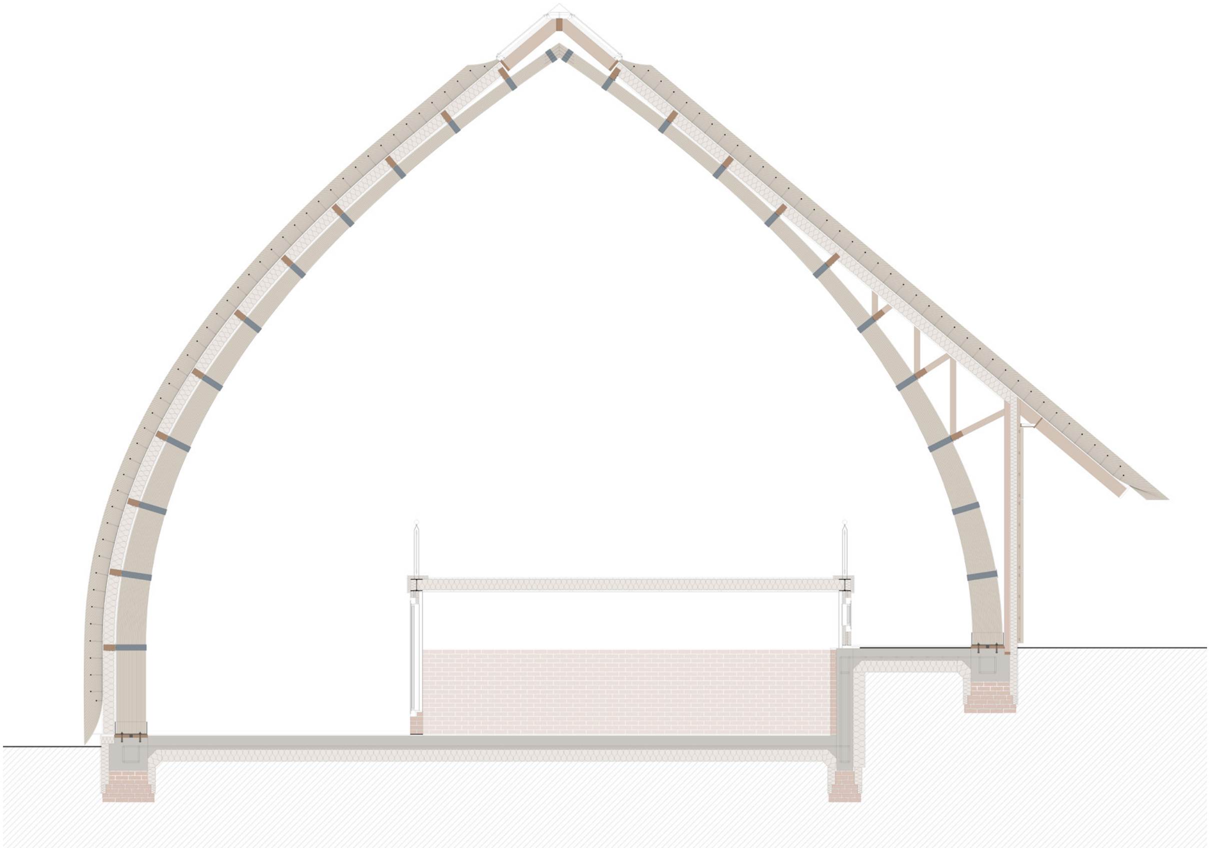


+0.5
Exposition
Cafe se
1 2 3 4 5 meter

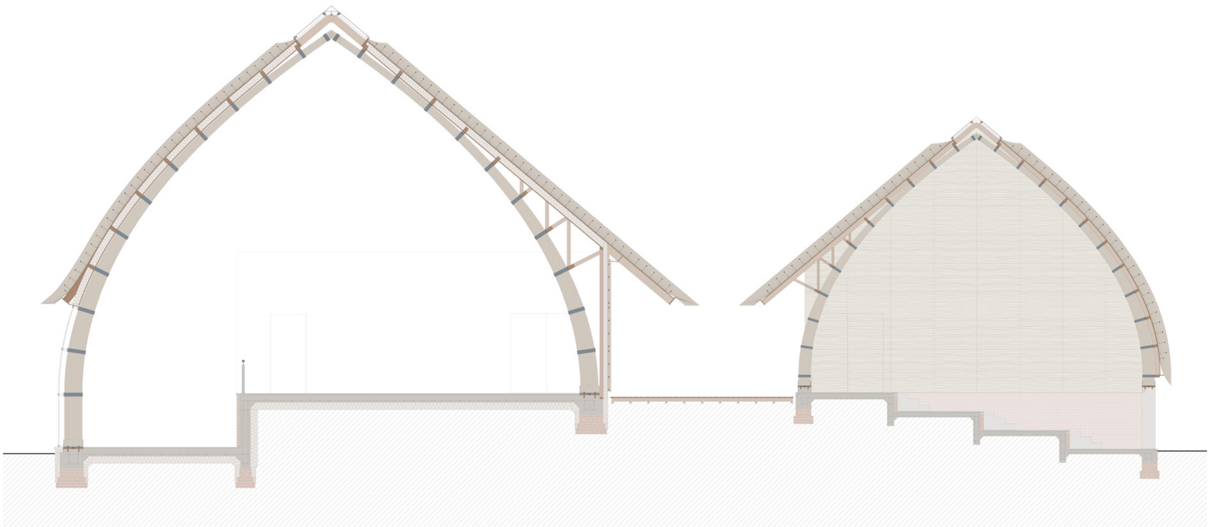

Entrance & Shop
Workshop
Bleachers
Storage
Lobby
Kitchen
Storage
ating


+1.5
Raised
exposition 2
1 2 3 4 5 meter


Technical space
Raised exposition 1

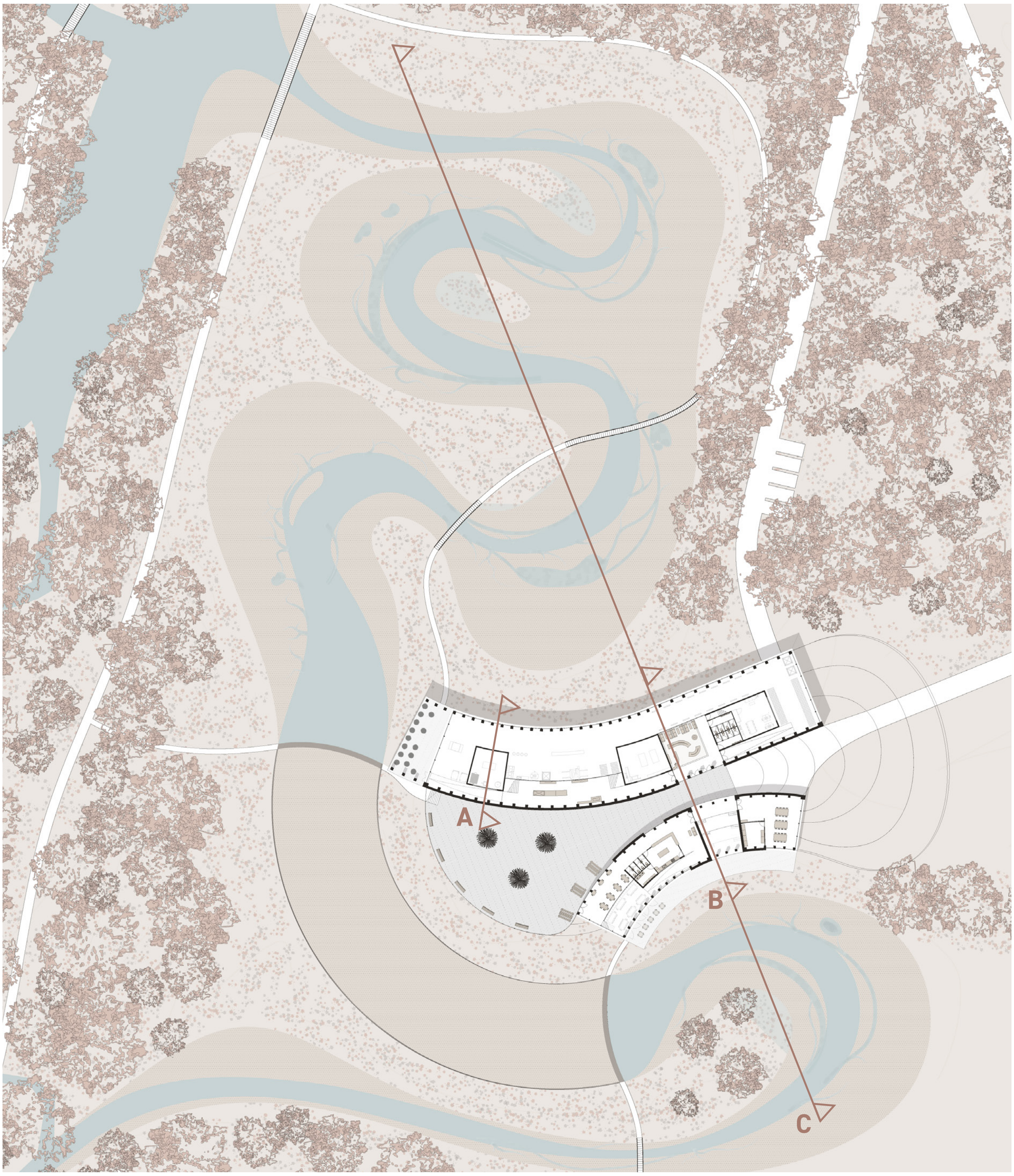


A



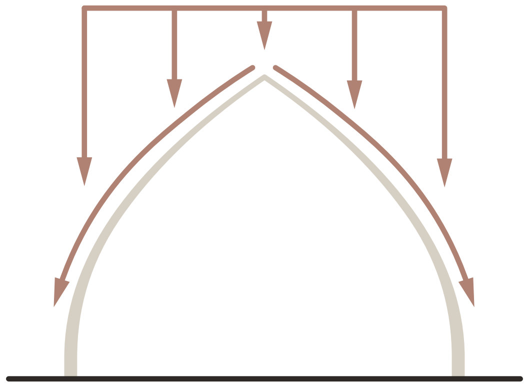
B

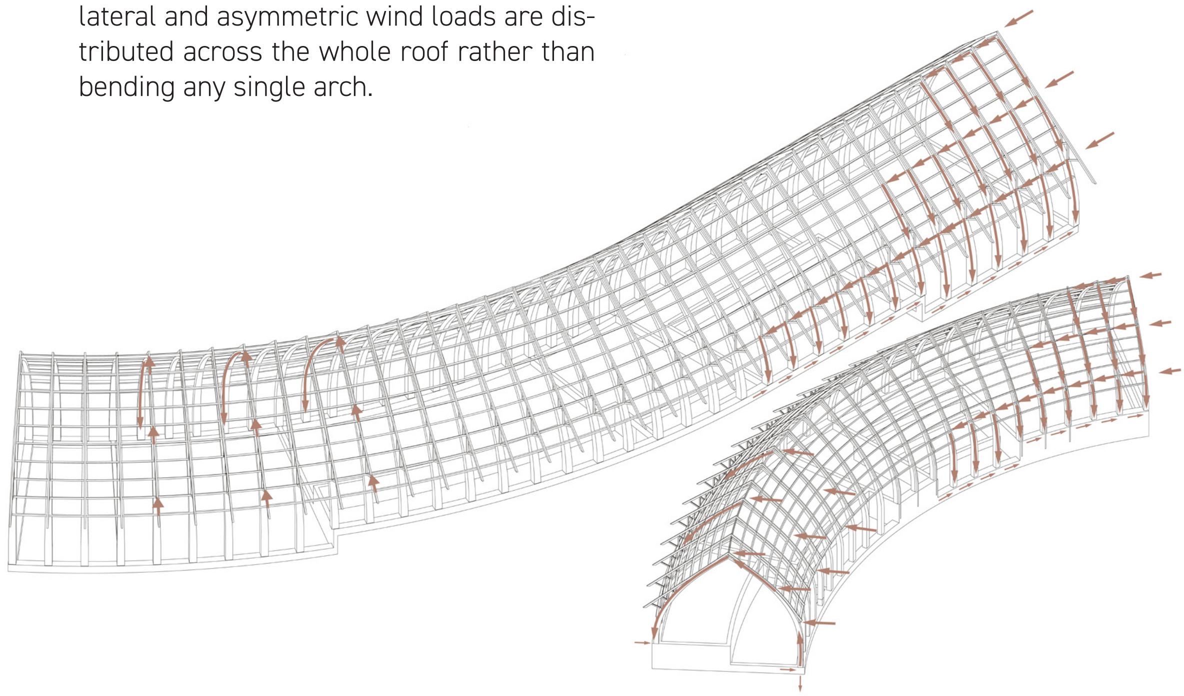
C

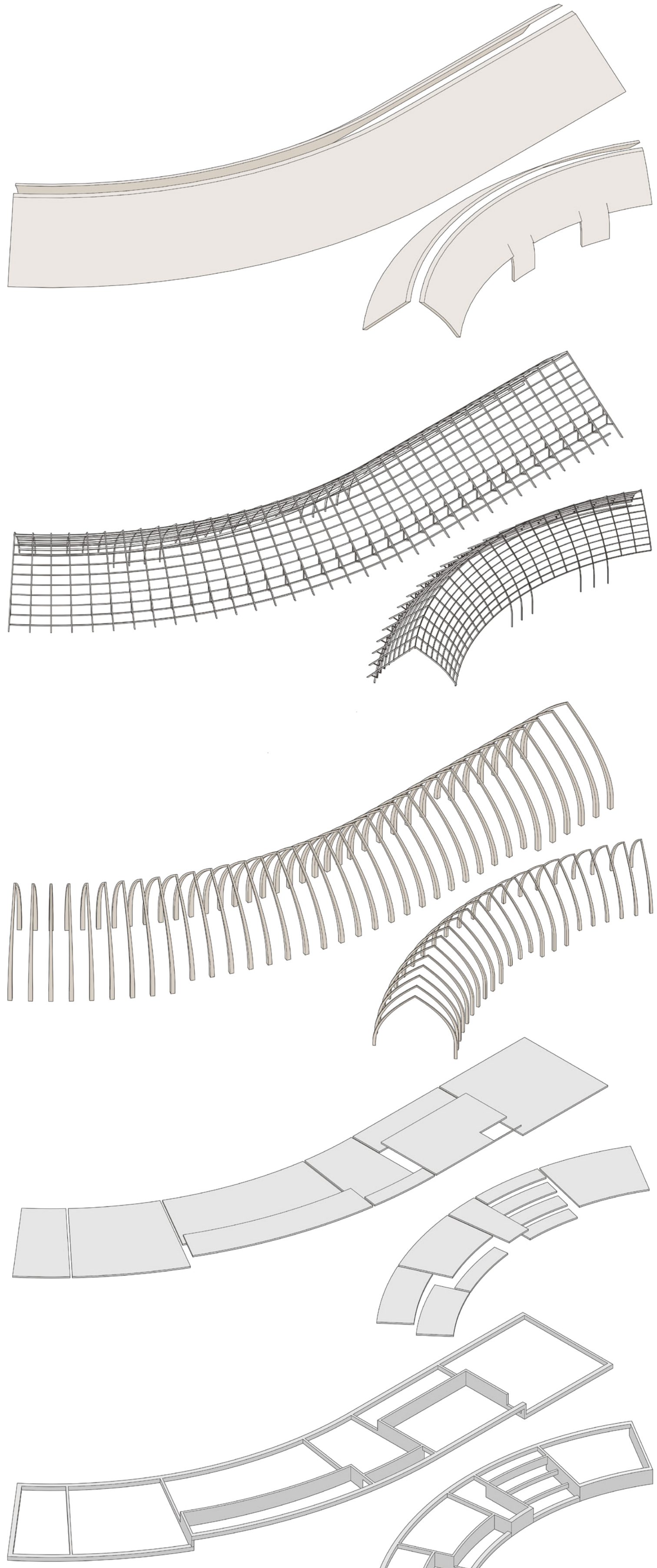

A
B
C

# Structure

A three-hinged gothic portal repeats every 2.4 m along each hall. The pointed profile is a structural choice; horizontal thrust falls as the arch rises, so the tall, sharply pointed gothic geometry pushes its load downward rather than outward, minimising the sideways force the supports must resist. Under combined gravity, snow, and wind, each portal carries a maximum axial compression of roughly 45 kN, with a horizontal thrust of about 10 kN per portal, very modest forces for the section sizes reed bundles require. The bundles taper from a 500 × 500 mm rooted base to a slender ~180–200 mm crown, an direct expression of how compression flows: heavy at the foot, converging upward as load diminishes. Crushing is negligible (≈12% utilisation) and buckling capacity vastly exceeds demand; the section is governed by stiffness and the reality of bundling reed, not by stress. Each portal foot is fixed to a continuous concrete ring beam, which holds the arches dimensionally stable and resolves the horizontal thrust as a closed ring rather than spreading footings. Wind, not gravity, governs stability, and it is met not by each portal alone but by the roof acting as one surface: the trusses and purlins tie every portal into a single rigid plane, so lateral and asymmetric wind loads are distributed across the whole roof rather than bending any single arch.

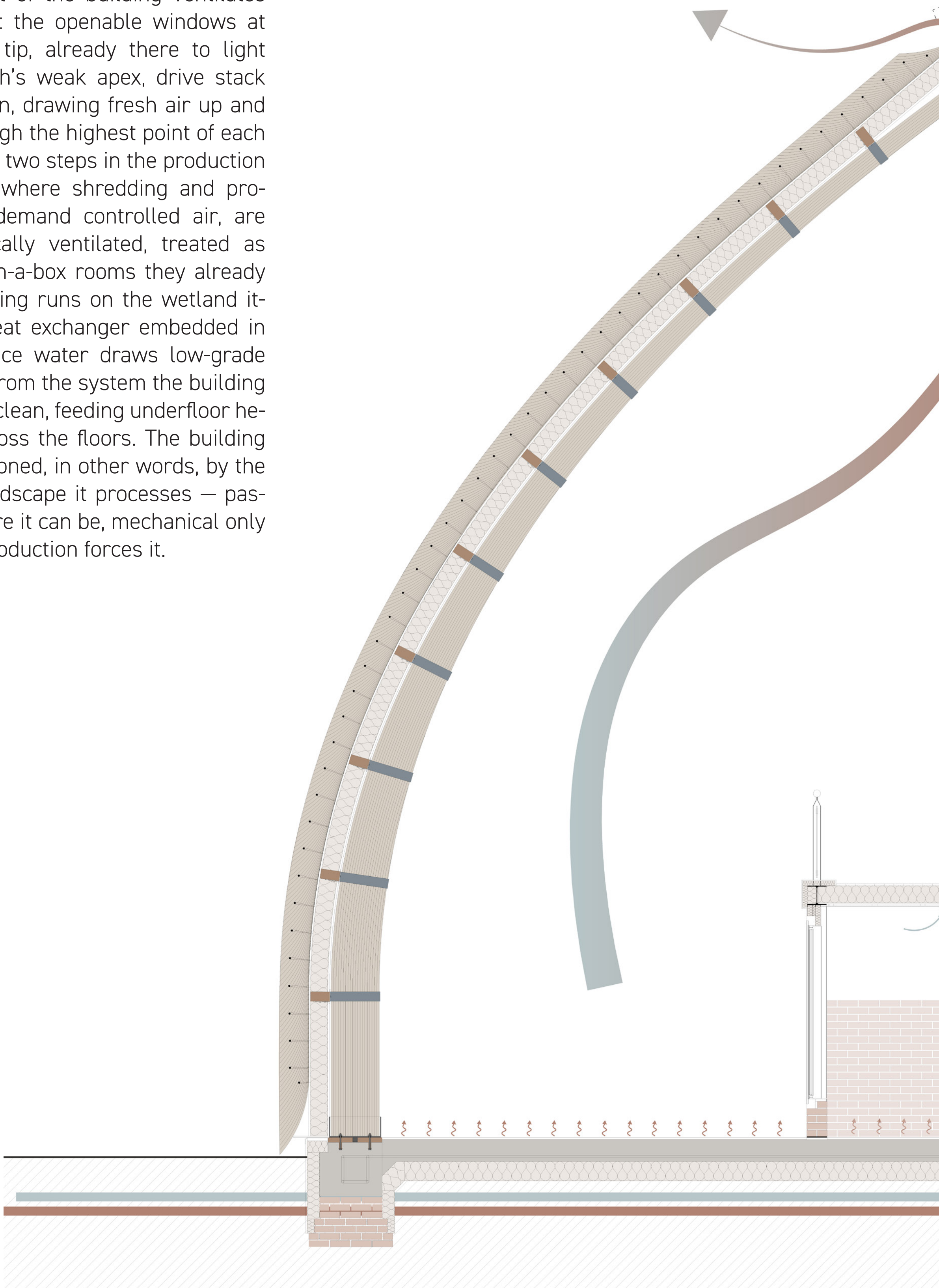


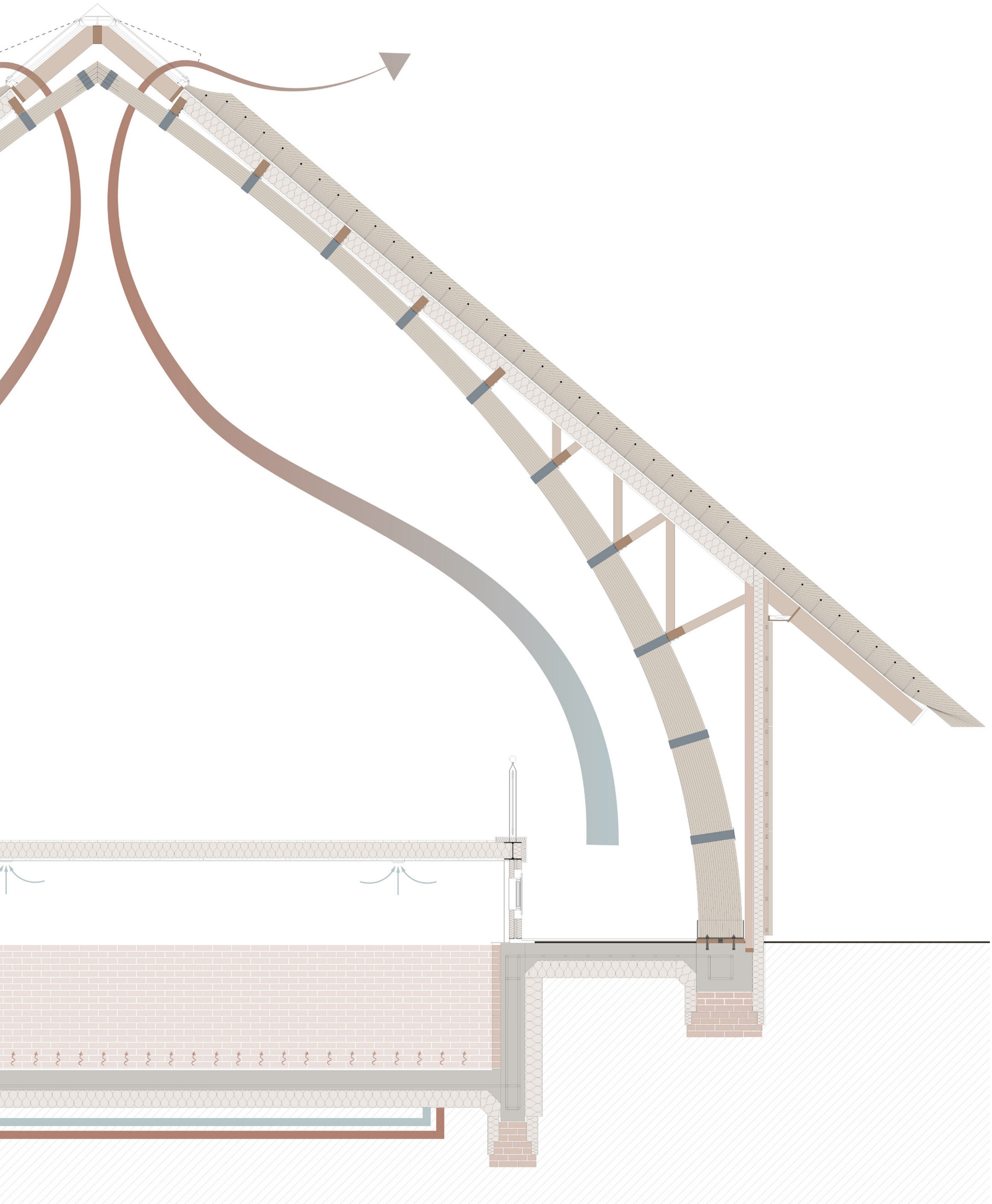


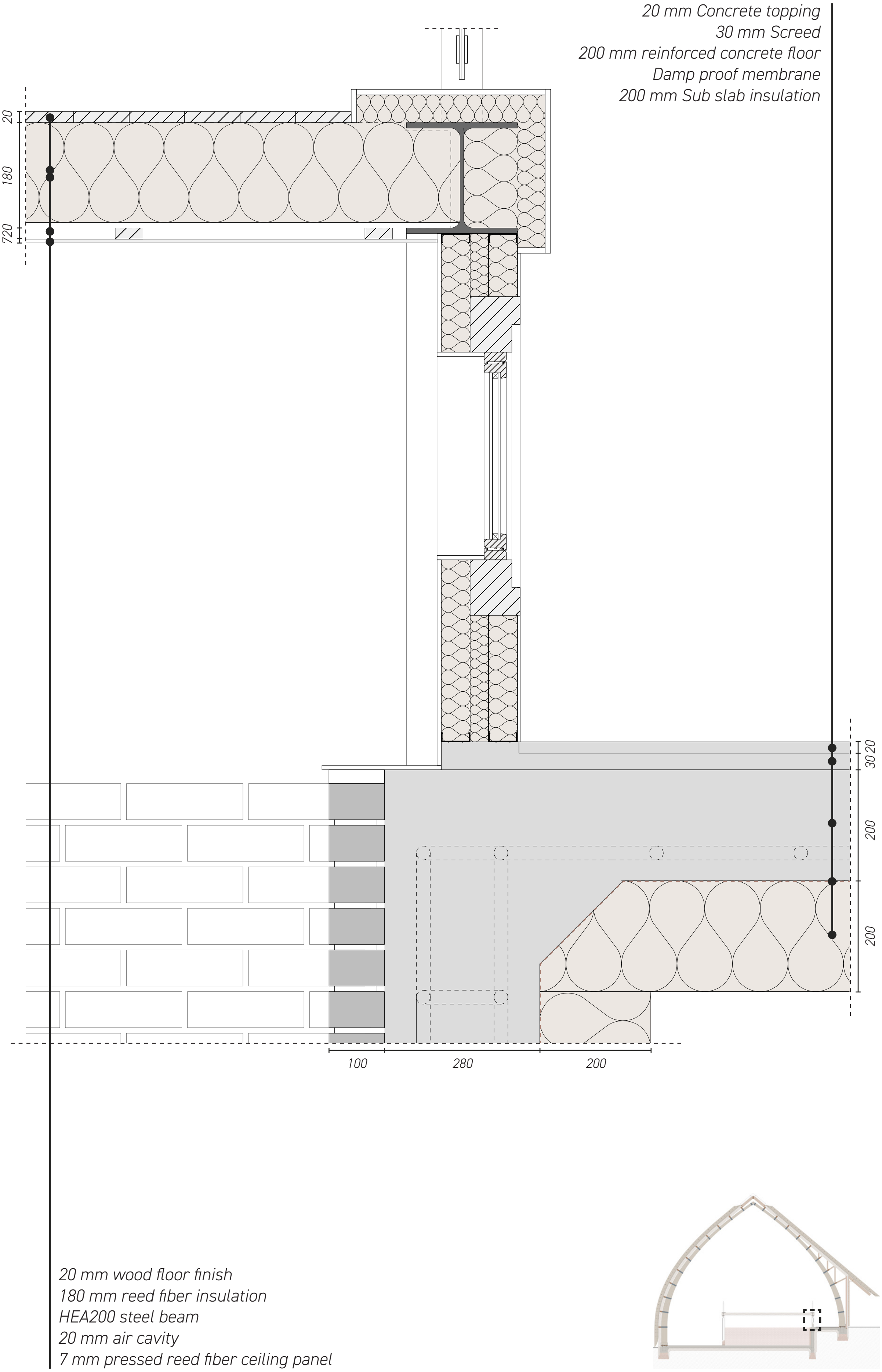


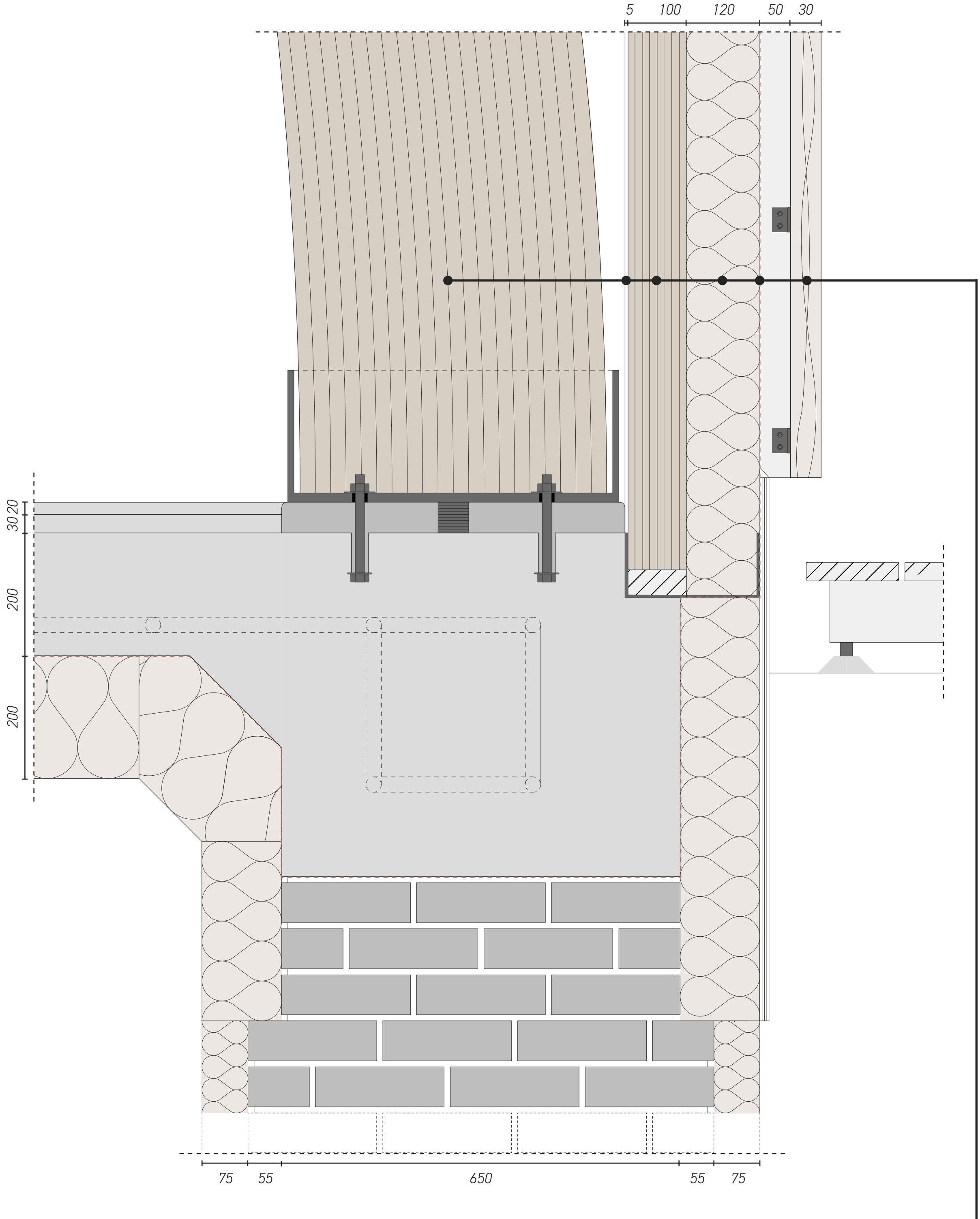
# Climate

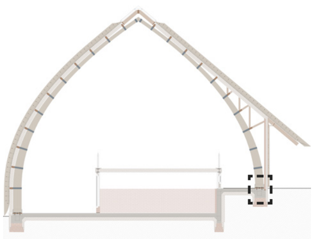
The climate strategy is deliberately low. Most of the building ventilates passively: the openable windows at the roof tip, already there to light the thatch's weak apex, drive stack ventilation, drawing fresh air up and out through the highest point of each hall. Only two steps in the production process, where shredding and processing demand controlled air, are mechanically ventilated, treated as the box-in-a-box rooms they already are. Heating runs on the wetland itself: a heat exchanger embedded in the surface water draws low-grade warmth from the system the building exists to clean, feeding underfloor heating across the floors. The building is conditioned, in other words, by the same landscape it processes — passive where it can be, mechanical only where production forces it.



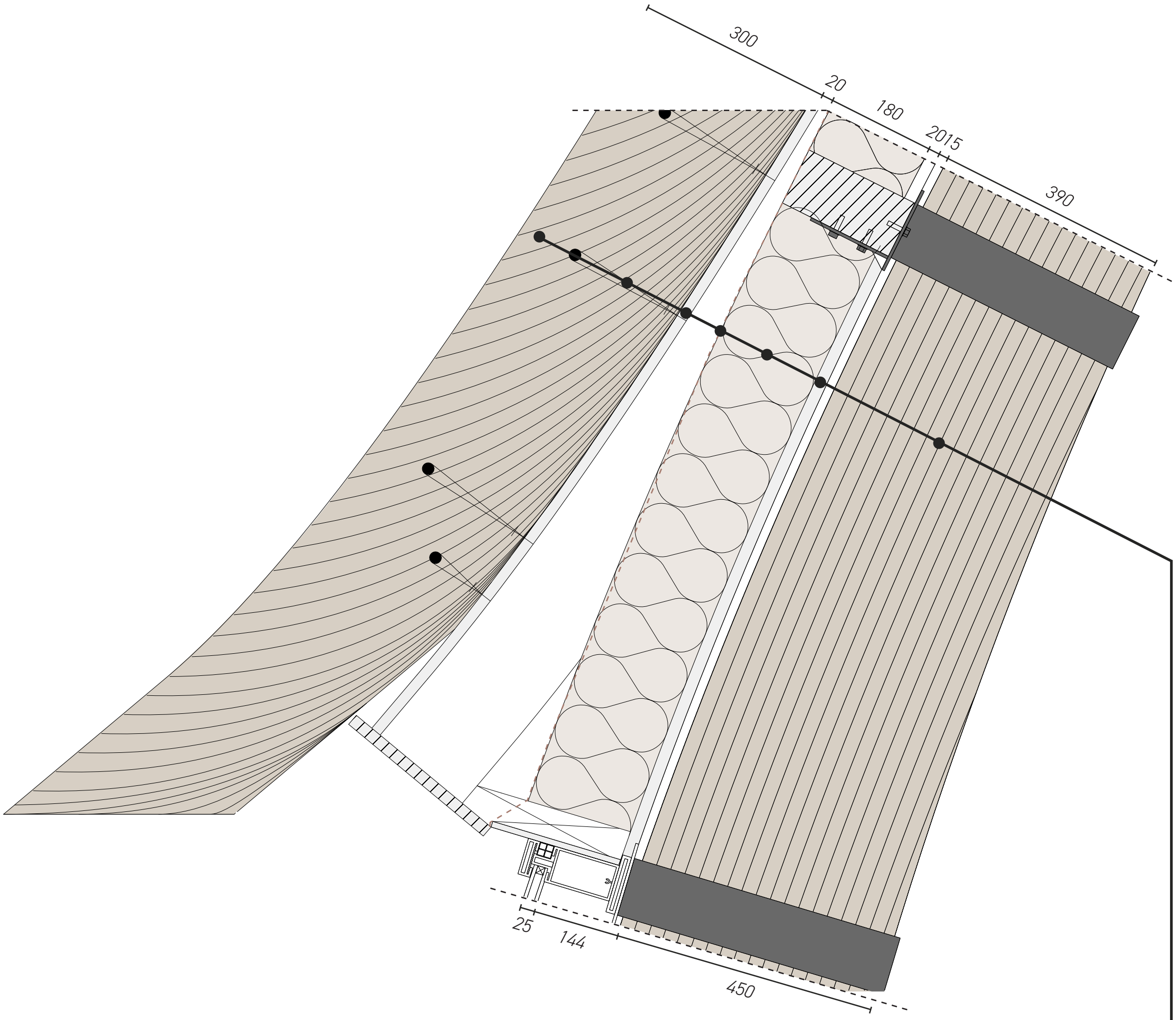



20 mm Concrete topping
30 mm Screed
200 mm reinforced concrete floor
Damp proof membrane
200 mm Sub slab insulation
20
180
720
30 20
200
200
100
280
200
20 mm wood floor finish
180 mm reed fiber insulation
HEA200 steel beam
20 mm air cavity
7 mm pressed reed fiber ceiling panel

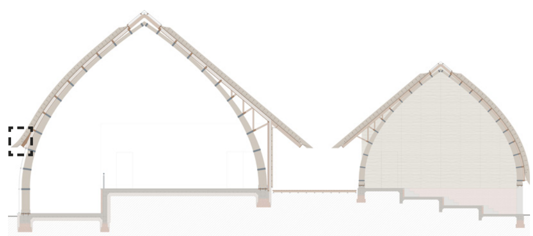


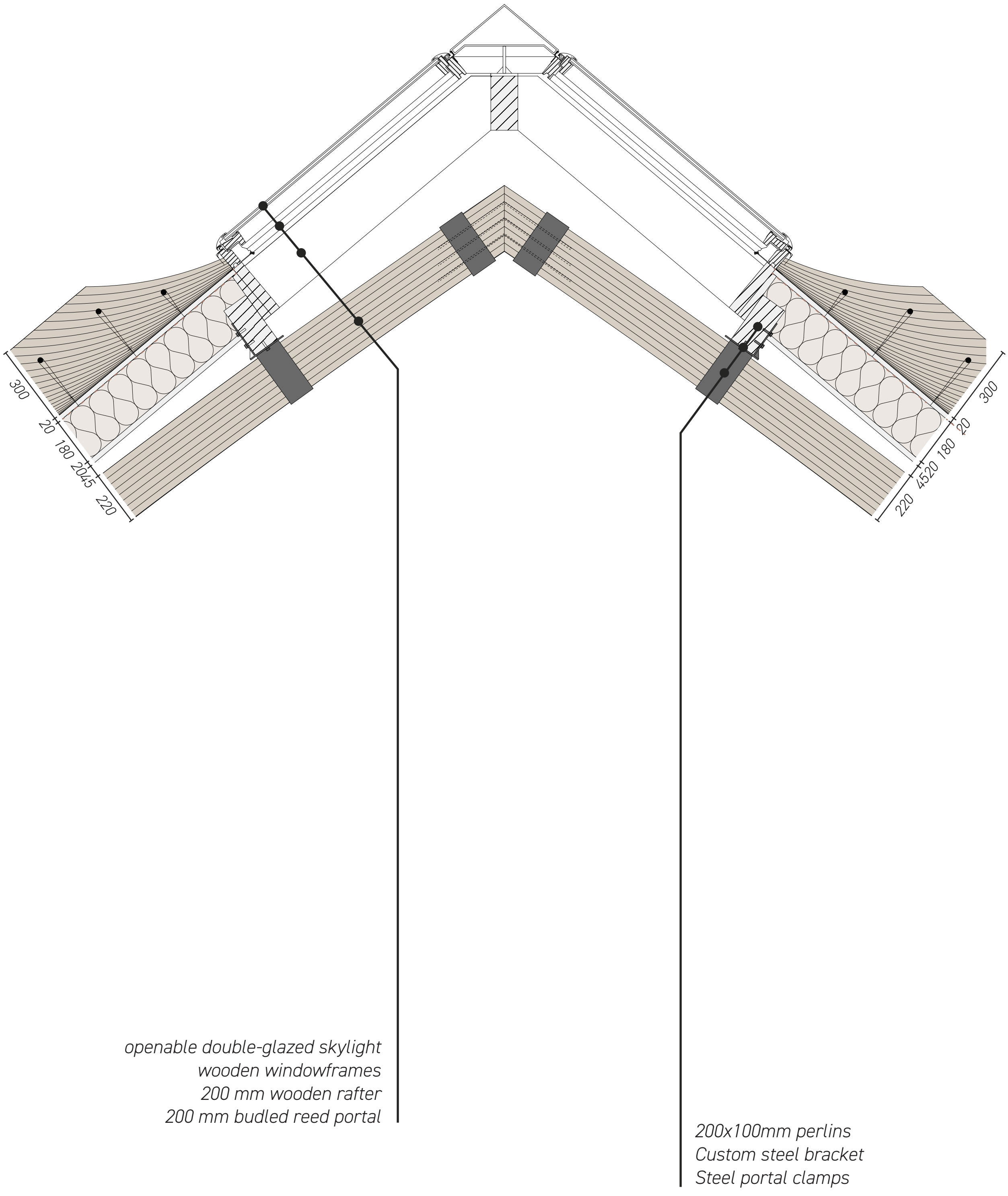



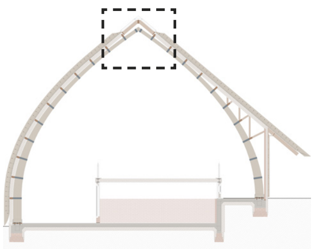
500 mm budled reed portal
5 mm pressed reed fiber interior panel
100 mm reed-clay infill
120 mm reed fiber insulation
damp open, water proof membrane
50 mm ventilation gap
30 mm pressed reed fiber facade panel




300 mm thatched roof
clamping bar
20 mm reedboard
180 mm reed fiber insulation
390 mm budled reed portal




300
20
180
20
45
220
300
20
180
45
20
220
openable double-glazed skylight
wooden windowframes
200 mm wooden rafter
200 mm budled reed portal
200x100mm perlins
Custom steel bracket
Steel portal clamps



REED PANELS
SUSTAINABLE BY NATURE

***So what***

*This chapter looks back and outward. It returns to the guiding questions to ask what the design actually demonstrated, honestly including its limits, and reflects on what the project means for the wider profession and on how the work was made.*

# Conclusion & Discussion

Conclusion

Architectural Contribution

process reflection

6

# Conclusion

My project set out to answer the question of *how a public building and its landscape could be designed as a single system that filters nitrogen from the Dommel, restores the nutrient-poor stream-valley ecology, and is itself built from the reed that process produces*. The design answers as a worked proposal, resolved from territorial scale down to façade details.

At the landscape scale, the four selected strategies; buffer strips, floodplain restoration, constructed wetland, and biomass harvesting, combine into one sequence that holds water, lowers nutrients, and rebuilds the conditions of the nineteenth-century beekdallandschap. The wetland is not a treatment plant disguised as nature; it brings back the historical water logic of the valley, the 'stuwschaduw' of the old watermills, returned in a contemporary form. The design shows that nitrogen mitigation and ecological restorationdon't have to be separate projects, the same intervention can serve both.

The numbers however, do set honest limits, and naming them has to be part of the answer. The Dommel carries roughly 273 tonnes of nitrogen a year; treating that load implies wetland on the order of tens of hectares, and harvesting the reed removes only an estimated 5–10% of what this system processes. One building does not solve the river. But the calculation also shows what the building is: not a filter sized to the problem, but a repeatable instance of a logic that could be distributed along the valley, and a place where the harvest, modest as a nitrogen sink, becomes valuable as material.

At the material scale, the work confirms that reed harvested from the wetland can be carried through most of a building. Whole stems thatch the roof; bundled stems span as mudhif-derived arches; loose fibre insulates; reed-clay buffers moisture; and pressed reed fibre forms a ventilated façade panel. The material is not theoretically viable but physically tested, pressed, modelled, and detailed. Its biodegradability, perhaps seen as a flaw, becomes one of the design's organising principles: a building made of an annually harvested crop is designed to be remade, not preserved.

At the architectural scale, the cycle is made visible. The visitor stands in the wetland that cleans the water, watches the reed that builds the walls being processed, and makes something from it by hand. The structure, envelope and programme are not a space to learn in; they are part of the lesson. This answers the fourth question, time, most directly: seasonality, harvest, and replacement are built into how the architecture works rather than fought as maintenance problems.

Measured against the introduction's twofold ambition, to buffer at the landscape scale and to make that process readable at the building scale, the project meets both, within the honest limit that it is a prototype and not a regional cure. It demonstrates that a building can run on the ecological process it teaches, and be built from it.

# Architectural Contribution

The value of a project like this is not that it would, if built, end the nitrogen crisis. It would not. Its importance is in pushing at the boundary of what is considered buildable, and doing the research to keep that push realistic rather than speculative. A proposal that is unusual but rigorously worked is more useful to the profession than either a safe design or an unbuildable fantasy.

Much of architecture advances not by inventing materials but by using existing ones differently, and several of this project's moves are small, transferable adjustments rather than wholesale inventions. The steel connectors that let bundled reed arches receive a roof structure adapt a five-thousand-year-old technique to contemporary use, the same hybridising move the living mudhif tradition itself made.

The ventilated reed façade brings several reed products, pressed panel, loose insulation, reed-clay infill, into a single buildable assembly, and standardises the panel so it can travel beyond this one building. None of these requires a new industry; each could be picked up by another designer in another context. The broader implication is more methodological. My project is an argument for an interdisciplinary approach to an architectural problem, one that treats hydrology, ecology, material science, and traditional craft as disciplines to design with. The synergy between a natural system and a local building material is not a sustainability slogan; it's the premise. If the project recommends anything to the field, it is to look harder at what the immediate landscape already produces, and to treat local biological material as a serious structural and architectural proposition rather than a finish.

Finally, the project suggests a model worth repeating: architecture as a node in an ecological cycle rather than an object placed beside one. The building that grows from, processes, and teaches its own material is a type that could be adapted wherever a degraded landscape produces a usable crop, which is in many more places than Eindhoven alone.

# Process reflection

I feel like the strength of my thesis, that it runs across three scales and disciplines, is also where its limits sit. Working at landscape, building, and material scale at once meant that no single scale could be taken as far as it deserved, and the shortened graduation period, ten weeks briefer than usual, sharpened that trade-off. Much of the reflection is therefore about depth I chose to defer rather than work I got wrong.

The material experiments are where I feel this most. The cold-pressing of façade panels produced real, testable results, but with more time I would have pushed the matrix much further: more binders and binder combinations, more fibre compositions, and ideally a collaboration with The Green Village to hot-press rather than cold-press the panels myself, which would likely have given stronger, more durable results. I would also have liked to properly test the finished panels for their physical and thermal properties, and to develop the ventilated reed façade toward an actual product rather than a proof of principle. There was also room to widen the material type itself, cattail from the same constructed wetlands, or timber from local rabattenbossen, turning a reed system into a fuller palette of local biomaterials.

The interdisciplinary reach was both the most rewarding and the most exposing part of the process. I repeatedly went way into other fields, forestry, hydrology, building technology, landscape design, far enough to inform the design, but I am aware I could have gone deeper into each. The landscape design in particular could have been developed much further: specific planting, species selection, and the pathing through the wetland are resolved at a strategic level rather than a detailed one.

On tools and methods, the parametric work was a success. The Grasshopper script let me generate and compare many slightly different façade-panel geometries quickly, and test them physically through 3D printing, exactly the kind of fast iteration the material study needed. Designing through making, rather than only drawing, suited the material questions and is something I would definitely carry into future work.

But the difficulty of working across so many scales and disciplines is, also why I find architecture so much fun. It is a little bit of everything, and the real task, the one this thesis was an attempt at, is making it technically feasable and bringing it all together into something coherent.

7

# Back Matter

Appendix

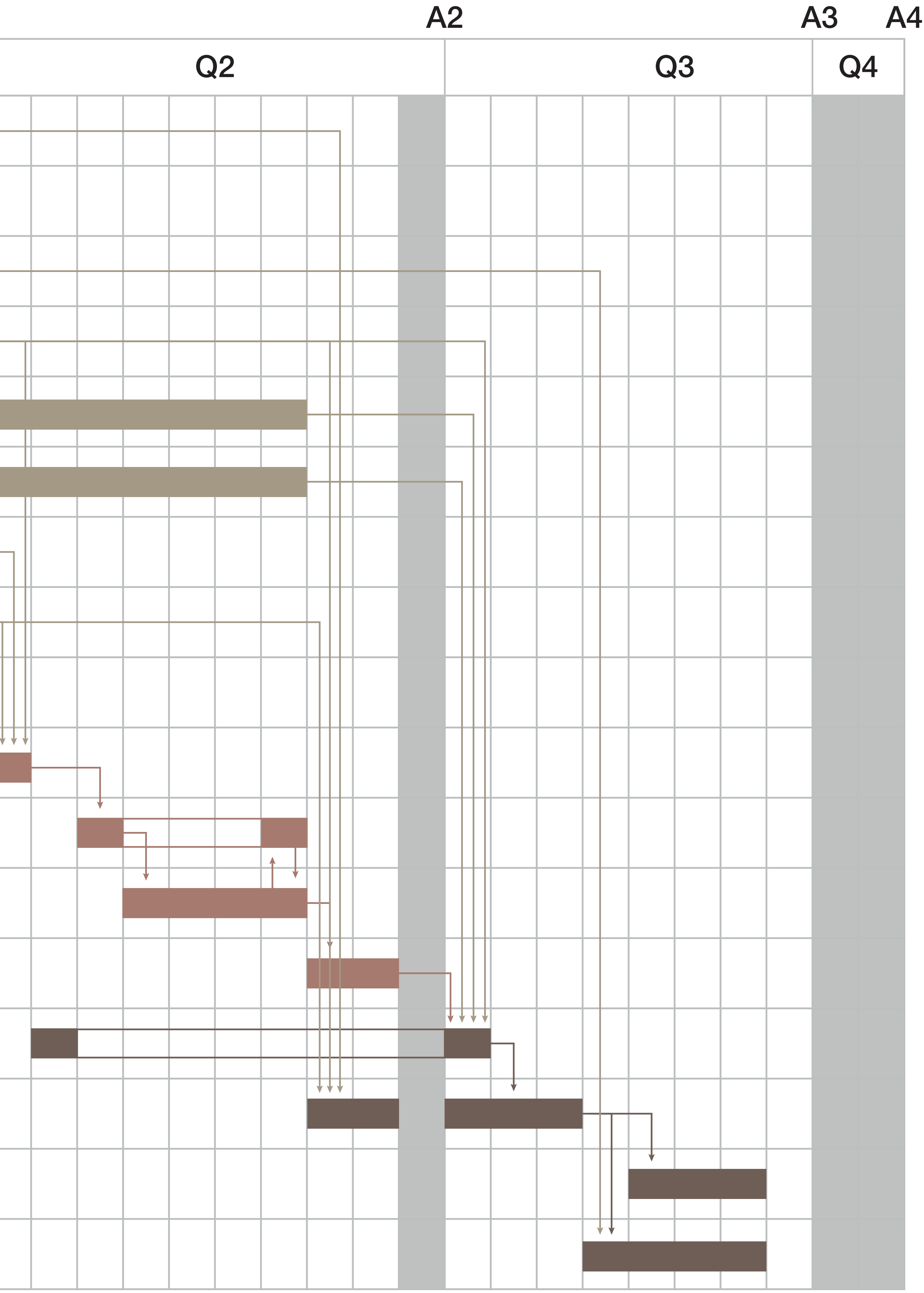
References& Images

AI-statement

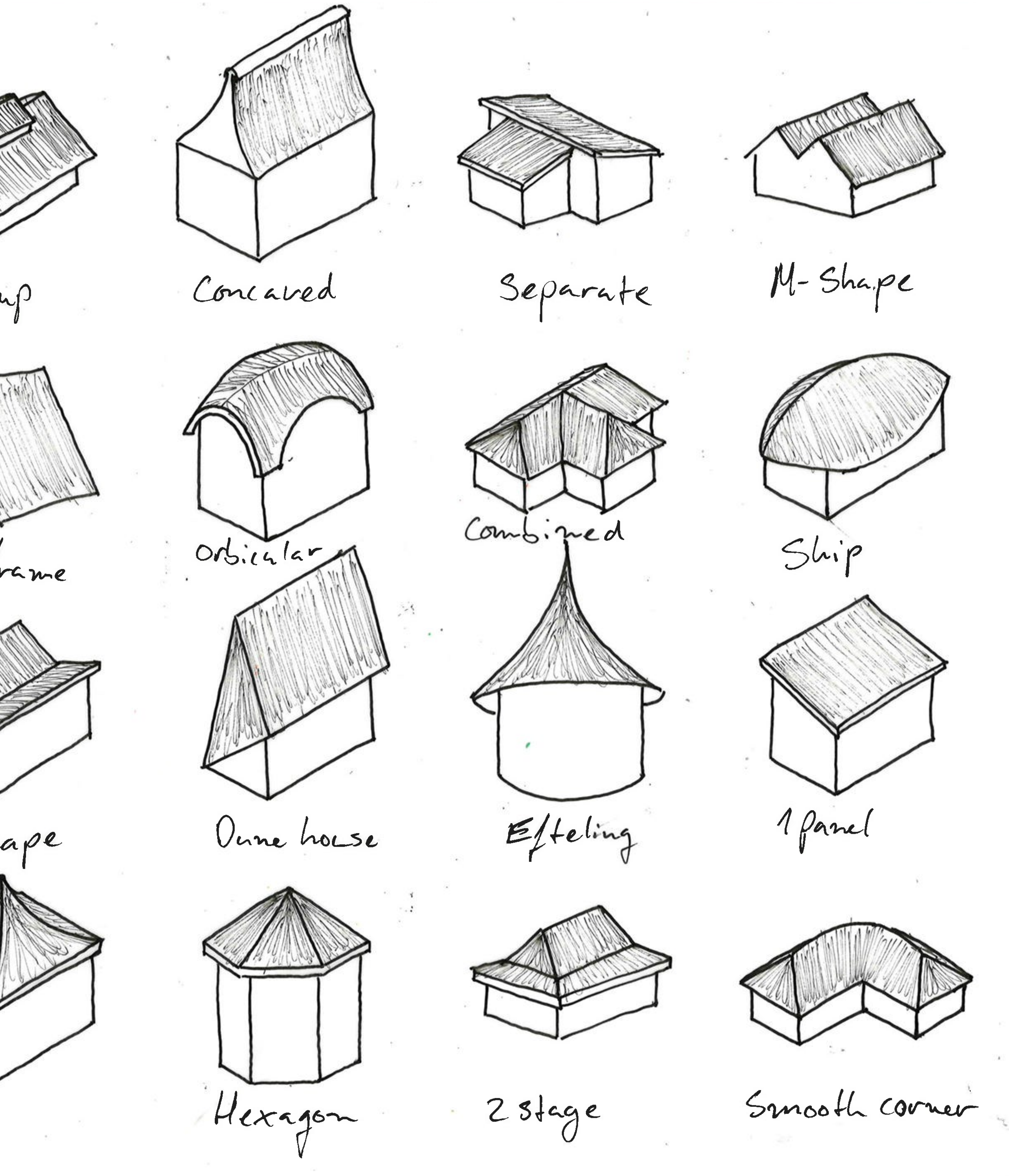
A1

| Framework | Research question | Task |
|---|---|---|
| TECHNICAL FRAMEWORK | *How do nitrogen emissions and deposition operate spatially in and around Eindhoven, and how are they linked to surrounding landscapes and protected nature?* | *Literature review* |
| | | *Policy review* |
| | | *Mapping* |
| | | *Site analysis* |
| | *How can architecture mediate between nitrogen policy, landscape processes, and public understanding through spatial design rather than technical regulation alone?* | *Literature review* |
| | | *Case studies* |
| | | *Nitrogen policy catalogue* |
| | *Which locally grown plant-based materials are suitable for architectural application in terms of availability, material behaviour, and ecological relevance?* | *Biomaterial catalogue* |
| | | *Biomaterial crop analysis* |
| RESEARCH BY DESIGN | *How can bio-based sandwich panels be architecturally applied, detailed, and assembled to expose their material logic rather than conceal it within standard construction?* | *Material selection* |
| | | *1:1 assembly* |
| | | *Application* |
| | | *Design translation* |
| | *How can a public building become an architectural landmark that spatially communicates nitrogen metabolism, material origin, and ecological processes?* | *Tectonic studies* |
| | | *Concept design* |
| | *- How can façade, roof, and interior details act as an exhibition of bio-based construction techniques and material transitions?* | *Integrated building design* |
| | | *Integrated landscape & logistics design* |

Q1


A2
A3
A4
Q2
Q3
Q4


Shield
asymetrical
Square Courtyard
Top-
offset
Industrial
Pyramid
A-
round courtyard
Dropped eaves
farmhouse
V-Sh
Shield
wolf
Organic openings
Swirl
Tipi


Concaved
Separate
M-Shape
Orbicular
Combined
Ship
Dune house
Efteling
1 panel
Hexagon
2 stage
Smooth corner

## 1. Livestock Reduction (Voluntary Buy-Outs)

*The government buys out farmers, especially near Natura 2000 areas, and permanently removes livestock and permits.*

| | |
|---|---|
| Timeline | |
| Cost | |
| Positive implications | |
| Negative implications | |

## 2. Nitrogen Emissions Trading System

*Creates a market where nitrogen emission rights can be traded between sectors (agriculture, industry, construction).*

| | |
|---|---|
| Timeline | |
| Cost | |
| Positive implications | |
| Negative implications | |

## 3. National Protein Transition (Dietary Shift)

*Policy-driven reduction of animal protein consumption; promotion of plant-based and alternative proteins.*

| | |
|---|---|
| Timeline | |
| Cost | |
| Positive implications | |
| Negative implications | |

## 4. Rewetting Peatlands (National Landscape Strategy)

*Raising groundwater levels to reduce nitrogen mineralization and emissions from peat soils*

| | |
|---|---|
| Timeline | |
| Cost | |
| Positive implications | |
| Negative implications | |

| |
|---|
| Short–medium term: 3–10 years |
| Very high, ~€20–40 billion nationally (current estimates) |
| • Direct and guaranteed nitrogen reduction<br>• Fast ecological recovery near protected areas<br>• Legal clarity for construction and infrastructure |
| • Social resistance and rural unrest<br>• Loss of agricultural knowledge and identity<br>• Risk of land speculation or monoculture afterward |

| |
|---|
| Medium term: 5–15 years |
| Medium (administrative + monitoring systems) |
| • Flexible, market-driven reduction<br>• Encourages innovation<br>• Allows targeted development where needed |
| • Risk of “pollution shifting” instead of reducing<br>• Complex governance<br>• Ethical concerns over commodifying nature |

| |
|---|
| Long term: 10–30 years |
| Medium (subsidies, education, food system changes) |
| • Structural reduction of livestock emissions<br>• Health and climate co-benefits<br>• Frees land for nature and housing |
| • Cultural resistance<br>• Slow behavioral change<br>• Unequal access to alternatives |

| |
|---|
| Medium–long term: 5–20 years |
| Medium–high (land acquisition, water infrastructure) |
| • Strong nitrogen and $CO_2$ reduction<br>• Biodiversity restoration<br>• Climate adaptation |
| • Loss of conventional agriculture<br>• Requires long-term land-use change<br>• Conflicts with existing infrastructure |

### 1. Precision Agriculture

*Use of sensors, GPS, AI, and data-driven fertilization to reduce excess nitrogen application.*

| | |
|---|---|
| **Timeline** | Sh |
| **Cost** | M |
| **Positive implications** | •<br>•<br>• |
| **Negative implications** | •<br>•<br>• |

### 2. Manure Processing & Nitrogen Recovery

*Manure is processed to extract ammonia or nitrogen compounds for reuse as fertilizer or industrial input.*

| | |
|---|---|
| **Timeline** | M |
| **Cost** | H |
| **Positive implications** | •<br>•<br>• |
| **Negative implications** | •<br>•<br>• |

### 3. Regional Livestock Redistribution

*Moving livestock away from Natura 2000 areas to less sensitive regions or reducing density regionally.*

| | |
|---|---|
| **Timeline** | M |
| **Cost** | M |
| **Positive implications** | •<br>•<br>• |
| **Negative implications** | •<br>•<br>• |

### 4. Agroforestry & Mixed Farming Systems

*Integrates trees, crops, and animals to improve nitrogen uptake and soil health.*

| | |
|---|---|
| **Timeline** | Lo |
| **Cost** | M |
| **Positive implications** | •<br>•<br>• |
| **Negative implications** | •<br>•<br>• |

| |
|---|
| hort–medium term: 2–8 years |
| edium (technology + training) |
| Reduces emissions without reducing production<br>Keeps farmers economically active<br>Scalable and incremental |
| Doesn't eliminate structural surplus<br>Tech dependency<br>Unequal access for small farms |

| |
|---|
| edium term: 5–10 years |
| igh (infrastructure + energy) |
| Circular nutrient economy<br>Reduces local nitrogen pressure<br>Potential new rural industries |
| Energy-intensive<br>Risk of shifting emissions elsewhere<br>Requires strong logistics network |

| |
|---|
| edium term: 5–15 years |
| edium–high |
| Spatially targeted impact<br>Preserves some agricultural activity<br>Enables regional planning strategies |
| Ethical concerns (problem displacement)<br>Infrastructure and transport emissions<br>Political complexity |

| |
|---|
| ong term: 10–30 years |
| edium |
| Nitrogen absorption through biomass<br>Biodiversity and landscape quality<br>Resilient rural systems |
| Slow return on investment<br>Knowledge-intensive<br>Hard to scale rapidly |

### 1. Barn-to-Housing Transformation

*Removing livestock and converting barns into housing, workspaces, or community functions.*

| | |
|---|---|
| **Timeline** | S |
| **Cost** | M |
| **Positive implications** | •<br>•<br>• |
| **Negative implications** | •<br>•<br>• |

### 2. Nitrogen-Absorbing Landscapes

*Constructed wetlands, reed beds, forests, algae systems that absorb nitrogen from air, water, or soil.*

| | |
|---|---|
| **Timeline** | M |
| **Cost** | L |
| **Positive implications** | •<br>•<br>• |
| **Negative implications** | •<br>•<br>• |

### 3. On-Site Ammonia Capture Systems

*Mechanical or bio-based systems capture ammonia from air or waste streams in buildings.*

| | |
|---|---|
| **Timeline** | S |
| **Cost** | M |
| **Positive implications** | •<br>•<br>• |
| **Negative implications** | •<br>•<br>• |

### 4. Circular Water–Nutrient Systems (Human Waste)

*Separating urine and wastewater to recover nitrogen for controlled reuse.*

| | |
|---|---|
| **Timeline** | M |
| **Cost** | M |
| **Positive implications** | •<br>•<br>• |
| **Negative implications** | •<br>•<br>• |

| |
|---|
| hort term: 1–5 years |
| edium (retrofit cheaper than new build) |
| Immediate local nitrogen reduction<br>Prevents rural decay<br>Reuses embodied carbon |
| Limited scale impact alone<br>Zoning and legal barriers<br>Risk of rural gentrification |

| |
|---|
| edium term: 5–10 years |
| ow–medium |
| Visible, spatial solution<br>Improves water quality<br>Can be integrated with housing |
| Limited absorption capacity<br>Requires land<br>Maintenance dependent |

| |
|---|
| hort term: 1–3 years |
| edium |
| Measurable nitrogen negativity<br>Fits experimental housing prototypes<br>Technological narrative |
| Still experimental<br>Energy and maintenance costs<br>Limited large-scale effect |

| |
|---|
| edium term: 3–10 years |
| edium |
| Expands nitrogen debate beyond agriculture<br>Strong research relevance<br>Fits future housing models |
| Cultural resistance<br>Regulatory barriers<br>Small absolute impact today |

Criteria:
- Local pro
- Architectu
- Nitrogen-
- Technolog

IMAGE OF MATERIAL

**1. MATERIAL/TECHNIQUE**
*'How it works' explanation for every material*

| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |

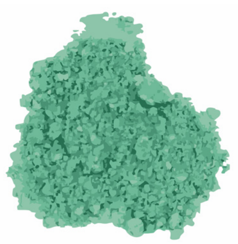
U
1
2
3
4

**1. Manganese oxides ($MnO_x$)**
*$MnO_x$ catalyzes the oxidation of NO into $NO_2$ and nitrates, accelerating nitrogen removal reactions.*

| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |

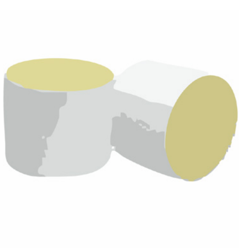
**2. Iron oxides ($Fe_2O_3$)**
*Iron oxide surfaces bind ammonia and facilitate redox reactions that transform reactive nitrogen into less mobile forms.*

| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |



**3. Copper oxides (CuO)**
*Copper sites strongly chemisorb ammonia, forming stable surface complexes that prevent re-release into the air.*

| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |



**4. Vanadium oxide SCR catalysts ($V_2O_5/TiO_2/WO_3$)**
*These catalysts enable ammonia to react selectively with $NO_x$, converting both into nitrogen gas and water.*

| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |

oducibility (NL / Brabant context)
ural applicability
reduction effectiveness ($NO_X$ / $NH_3$ / $NO_3^-$)
gical maturity (TRL)

| | Gr. | Summary |
|---|---|---|
| ility | 1 | Were it can be produced |
| | 2 | Were it can be applied |
| | 3 | What it absorbs/adsorbs ($NO_X$, $NH_3$, $NH_4^+$) and how much |
| | 4 | In what inustry is it used |

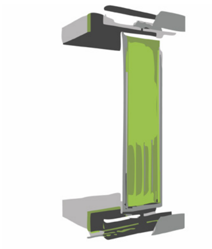
**nified grading system (1–4 applied to all criteria):**
= very low / experimental / difficult
= moderate / limited / context-dependent
= high / proven / broadly usable
= very high / optimized / scalable

| | Gr. | Summary |
|---|---|---|
| ility | 2 | Catalysts imported; integration locally possible |
| | 2 | Air filters, catalytic panels |
| | 4 | Very strong $NO_X$ reduction |
| | 4 | Used industrially |

| | Gr. | Summary |
|---|---|---|
| ility | 4 | Abundant; NL steel industry by-product potential |
| | 3 | Filters, composite materials |
| | 3 | Moderate but cheap & safe |
| | 4 | Commercial |

| | Gr. | Summary |
|---|---|---|
| ility | 2 | Can be produced from scrap copper |
| | 2 | $NH_3$ filters, catalytic coatings |
| | 4 | Very strong ammonia adsorption |
| | 4 | Used industrially |

| | Gr. | Summary |
|---|---|---|
| ility | 1 | Specialized production |
| | 1 | Mechanical ventilation systems, industrial-scale exhaust treatment |
| | 4 | Gold standard for $NO_X$ reduction |
| | 4 | Widely commercial |



## 1. Algae bioreactors

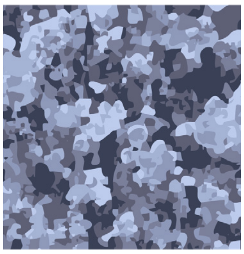
*Algae assimilate nitrates and ammonia into biomass during growth, permanently removing reactive nitrogen from water or air streams.*

| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |

## 2. Moss façade systems

*Moss absorbs NO and ammonia directly through its surface while hosting microbes that convert nitrogen into biomass.*

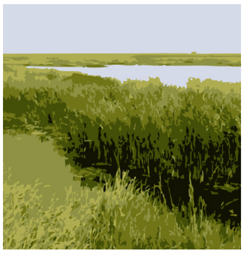
| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |



## 3. Lichen substrates

*Lichens absorb nitrogen directly from air without roots, making them extremely sensitive and effective NO sinks.*

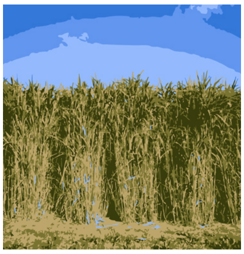
| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |



## 4. Constructed wetlands / reed beds / willow systems

*Plants absorb nitrogen while anaerobic microbes convert nitrates into nitrogen gas through denitrification.*

| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |



## 5. Miscanthus / hemp / fast-growing crops

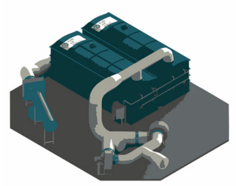
*These plants uptake large amounts of nitrogen during growth, which becomes stored in harvested biomass used as building material.*

| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |

## 6. Mycelium composites

*Fungal networks immobilize nitrogen within organic structures and bind ammonium in the substrate during growth.*

| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |



## 7. Air & biofilter assemblies

*Combine adsorption, microbial activity, and sometimes catalysis to continuously capture and transform nitrogen pollutants as air or water passes through.*

| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |

| | Gr. | Summary |
|---|---|---|
| ility | 3 | Dutch companies already produce algae systems |
| | 3 | Façade bioreactors, greenhouse roofs, water treatment |
| | 4 | Removes nitrates, ammonia --> biomass |
| | 3 | Piloted in Europe; semi-commercial |

| | Gr. | Summary |
|---|---|---|
| ility | 4 | Moss naturally grows in NL; substrate systems available |
| | 4 | Façades, green walls, biofilters |
| | 3 | Good at $NO_2$ and $NH_3$ uptake |
| | 4 | Commercial green-wall solutions exist |

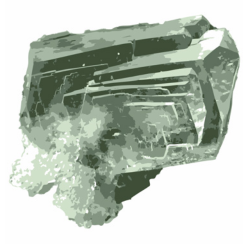
| | Gr. | Summary |
|---|---|---|
| ility | 2 | Naturally occurs but not industrially grown |
| | 2 | Niche façade modules, interior biofilters |
| | 4 | Excellent $NO_2$ absorption |
| | 1 | Limited commercial use |

| | Gr. | Summary |
|---|---|---|
| ility | 4 | Reeds, willows, Miscanthus common in NL |
| | 4 | Wetland roofs, water treatment, landscape integration |
| | 4 | Very strong nitrate --> $N_2$ removal |
| | 4 | Established technology |

| | Gr. | Summary |
|---|---|---|
| ility | 4 | Can be made from Dutch biomass (wood, sewage sludge, agri waste). |
| | 3 | Interior filters, façade filter modules, ventilation systems |
| | 3 | Especially for ammonia |
| | 4 | Fully commercial |

| | Gr. | Summary |
|---|---|---|
| ility | 4 | Brabant has active mushroom industry & agri-waste |
| | 3 | Interior panels, insulating blocks, acoustic materials |
| | 2 | Stores N in biomass; slight adsorption |
| | 3 | Emerging products available |

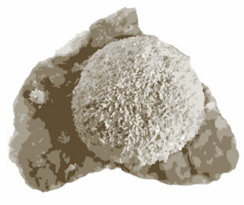
| | Gr. | Summary |
|---|---|---|
| ility | 3 | Imported powder, processed locally |
| | 4 | Paints, plasters |
| | 3 | Stable, good $NO_2$ oxidation |
| | 4 | Advanced research --> early commercial |



### 1. Clinoptilolite (natural zeolite)

*Its porous crystal structure traps ammonium ions ($NH_4^+$) through ion exchange, especially effective in water and moist air systems.*

| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |



### 2. Mordenite (MOR)

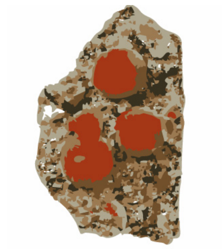
*Narrow pore channels selectively adsorb ammonia molecules and hold them via electrostatic attraction.*

| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |

### 3. Chabazite (CHA)

*CHA binds ammonia strongly and is often used to temporarily store $NH_3$ in catalytic systems where it later reacts with $NO_x$.*

| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |



### 4. Ferrierite (FER)

*Adsorbs ammonia and supports catalytic reactions that convert $NO_x$ into harmless nitrogen and water*

| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |

### 5. Activated carbon

*Its extremely high surface area physically adsorbs ammonia and $NO_x$; surface treatments enhance chemical binding of nitrogen compounds.*

| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |

### 6. Biochar

*Biochar's porous carbon matrix adsorbs ammonium and nitrate while also immobilizing nitrogen in stable organic forms.*

| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |

### 7. Bentonite (montmorillonite)

*Layered clay sheets carry negative charges that bind positively charged ammonium ions through cation exchange.*

| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |

| | Gr. | Summary |
|---|---|---|
| ility | 2 | No Dutch deposits, but easy EU import; processing locally |
| | 3 | Biofilters, drainage layers, wall panels |
| | 3 | Strong ammonium adsorption |
| | 4 | Fully commercial |

| | Gr. | Summary |
|---|---|---|
| ility | 1 | Synthetic or imported minerals |
| | 2 | Air filters, catalytic substrates, wall cassettes |
| | 4 | Very strong $NH_3$ /$NO_X$ adsorbtion |
| | 4 | Used in industry |

| | Gr. | Summary |
|---|---|---|
| ility | 1 | Synthetic or imported minerals |
| | 2 | Air filters, catalytic substrates, wall cassettes |
| | 4 | Especially used in automotive $NH_3$/$NO_X$ catalysts |
| | 4 | Used in industry |

| | Gr. | Summary |
|---|---|---|
| ility | 1 | Synthetic or imported minerals |
| | 2 | Air filters, catalytic substrates, wall cassettes |
| | 3 | Strong $NH_3$ /$NO_X$ adsorbtion |
| | 4 | Used in industry |

| | Gr. | Summary |
|---|---|---|
| ility | 4 | Can be made from Dutch biomass (wood, sewage sludge, agri waste). |
| | 3 | Interior filters, façade filter modules, ventilation systems |
| | 4 | Especially for ammonia |
| | 4 | Fully commercial |

| | Gr. | Summary |
|---|---|---|
| ility | 4 | Can be made locally from elephant grass, hemp, straw, forest prunings. |
| | 3 | Soil layers, green roofs, façade substrates |
| | 3 | Good ammonium & nitrate adsorptio |
| | 3 | Widely used in environmental applications |

| | Gr. | Summary |
|---|---|---|
| ility | 2 | NL has some clay production; most specialty clays imported |
| | 3 | Green-roof substrates, interior plasters, biofilters |
| | 2 | Moderate $NH_4^+$ adsorption |
| | 4 | Commercial |

## 8. Kaolinite

*Binds ammonium weakly via surface adsorption; mainly useful as a stabilizing matrix rather than a primary absorber.*

| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |

## 9. Illite

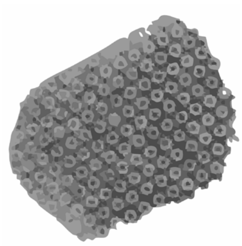
*Traps ammonium ions between clay layers, storing nitrogen in soils or substrate systems.*

| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |

## 10. Sepiolite

*Its fibrous microstructure physically traps ammonia molecules within internal channels.*

| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |



## 11. MOFs (HKUST-1, UiO-66, MIL-101, MIL-100)

*Metal nodes chemically bind ammonia or $NO_x$ within highly ordered nano-pores, achieving extremely high storage per volume.*

| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |

| | Gr. | Summary |
|---|---|---|
| ility | 2 | NL has some clay production; most specialty clays imported |
| | 3 | Green-roof substrates, interior plasters, biofilters |
| | 1 | Low $NH_4^+$ adsorption |
| | 4 | Commercial |

| | Gr. | Summary |
|---|---|---|
| ility | 2 | NL has some clay production; most specialty clays imported |
| | 3 | Green-roof substrates, interior plasters, biofilters |
| | 2 | Moderate $NH_4^+$ adsorption |
| | 4 | Commercial |

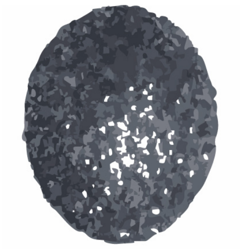
| | Gr. | Summary |
|---|---|---|
| ility | 1 | NL has some clay production; most specialty clays imported |
| | 2 | Green-roof substrates, interior plasters, biofilters |
| | 3 | Good $NH_4^+$ adsorption |
| | 4 | Commercial |

| | Gr. | Summary |
|---|---|---|
| ility | 1 | Difficult production; imported |
| | 2 | Embedded into filter membranes or experimental façade panels |
| | 4 | Excellent $NH_3$ and NO adsorption |
| | 1 | Mostly experimental/prototype |

### 1. Titanium dioxide ($TiO_2$) coatings & cements

*Under UV light, $TiO_2$ acts as a photocatalyst that oxidizes NO and $NO_x$ in the air into nitrates, which are then washed away by rain or captured in the material surface.*

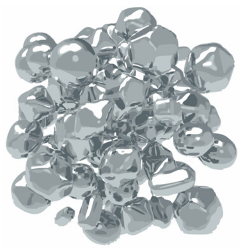
| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |



### 2. $TiO_2$-doped asphalt / paving

*Functions like $TiO_2$ concrete, but positioned horizontally where traffic emissions are highest, converting $NO_x$ into less harmful nitrate compounds.*

| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |



### 3. Zinc oxide (ZnO) coatings

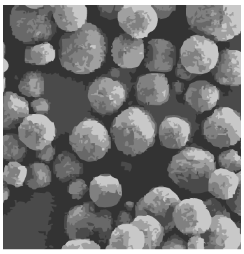
*ZnO absorbs light and generates reactive surface radicals that break down $NO_x$ gases into oxidized nitrogen compounds.*

| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |

### 4. Tungsten oxide ($WO_3$) coatings

*$WO_3$ is activated by visible light, making it effective under cloudy or low-UV conditions, oxidizing $NO_x$ into surface-bound nitrates.*

| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |



### 5. Ceria-based photocatalysts ($CeO_2$)

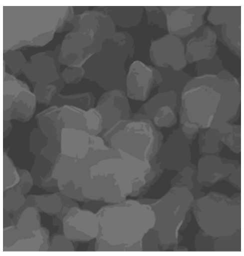
*$CeO_2$ alternates between oxidation states, enabling it to repeatedly bind and oxidize $NO_x$ molecules without being consumed.*

| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |

### 6. Graphitic carbon nitride (g-$C_3N_4$)

*This polymeric semiconductor absorbs visible light and drives photocatalytic reactions that degrade $NO_x$ on coated surfaces.*

| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |



### 7. Perovskite photocatalysts ($BaTiO_3$, $SrTiO_3$)

*Their crystalline structure facilitates charge separation under light, enabling highly efficient oxidation of $NO_x$ at the surface.*

| Criterion |
|---|
| Local producab |
| Applicability |
| Effectiveness |
| TRL |

| | Gr. | Summary |
|---|---|---|
| ility | 3 | $TiO_2$ itself is imported, but coatings/cements manufactured locally (e.g., NL concrete industry, paints) |
| | 4 | Façades, roofing tiles, pavements, interior paints (less effective indoors) |
| | 4 | Very strong $NO_X$ reduction in sunlight |
| | 4 | Fully commercialized, widely used in NL infrastructure. |

| | Gr. | Summary |
|---|---|---|
| ility | 3 | Asphalt production in Noord-Brabant can integrate $TiO_2$ additives |
| | 3 | Paving around the building site; external hardscapes |
| | 3 | $NO_X$ reduction depends on UV exposure & surface wear |
| | 4 | Field tested and implemented in EU pilot roads |

| | Gr. | Summary |
|---|---|---|
| ility | 2 | ZnO imported but coating made locally |
| | 3 | Façade paints, transparent coatings |
| | 3 | Visible-light active but generally slightly less efficient than $TiO_2$ |
| | 3 | Commercial in specialty paints |

| | Gr. | Summary |
|---|---|---|
| ility | 1 | Materials imported; coating production possible locally |
| | 3 | Façades in low-UV climates |
| | 4 | Excellent visible-light performance; stable |
| | 2 | Pilot-stage, some commercial prototypes |

| | Gr. | Summary |
|---|---|---|
| ility | 2 | Imported powder, processed locally |
| | 3 | Paints, plasters |
| | 3 | Stable, good $NO_2$ oxidation |
| | 2 | Advanced research --> early commercial |

| | Gr. | Summary |
|---|---|---|
| ility | 2 | Can be synthesized from urea locally |
| | 2 | Coatings, interior photocatalytic panels |
| | 3 | Moderate, visible-light responsive |
| | 2 | Emerging; few commercial uses |

| | Gr. | Summary |
|---|---|---|
| ility | 1 | Requires specialized synthesis |
| | 2 | High-performance coatings, research façades |
| | 4 | Lab-proven strong $NO_X$ reduction |
| | 1 | emerging; few commercial uses |

# References

A modern visitor centre using old techniques by Lake Tåkern. - Trä magazine. (z.d.). Swedish Wood. https://www.swedishwood.com/publications/wood-magazine/2012-3/a_modern_visitor_centre_using_old_techniques_by_lake_takern/

Ali, A., Jabeen, N., Farruhbek, R., Chachar, Z., Laghari, A. A., Chachar, S., Ahmed, N., Ahmed, S., & Yang, Z. (2025). Enhancing nitrogen use efficiency in agriculture by integrating agronomic practices and genetic advances. Frontiers in Plant Science, 16, Article 1543714. https://doi.org/10.3389/fpls.2025.1543714

Bakatovich, A., Gaspar, F., & Boltrushevich, N. (2022). Thermal insulation material based on reed and straw fibres bonded with sodium silicate and rosin. Construction and Building Materials, 352, 129055. https://doi.org/10.1016/j.conbuildmat.2022.129055

Boezeman, D., de Pue, D., Graversgaard, M., & Möckel, S. (2023). Less livestock in north-western Europe? Discourses and drivers behind livestock buyout policies.

EuroChoices, 22(1), 4–12. https://doi.org/10.1111/1746-692X.12399
Brockholes Visitor Centre ← Projects ← Adam Khan Architects. (z.d.). https://adamkhan.co.uk/projects/brockholes/

Centraal Bureau voor de Statistiek. (2026, 8 april). Monitor fosfaat- en stikstofexcretie in dierlijke mest, vierde kwartaal 2025. Centraal Bureau voor de Statistiek. https://www.cbs.nl/nl-nl/longread/aanvullende-statistische-diensten/2026/monitor-fosfaat-en-stikstofexcretie-in-dierlijke-mest-vierde-kwartaal-2025

De Mars, H., & Bleumink, H. (2022). Het Dommeldal: een eeuwenoude cascade van watermolenlandschappen (Vol. B) [Digitaal]. Watermolenlandschappen. https://www.watermolenlandschappen.nl/

Erisman, J. W., Strootman, B., Bastmeijer, K., Jongeneel, R., Poppe, K., Van den Wittenboer, S., & Van Dorp, M. (2021). Naar een ontspannen Nederland: hoe het oplossen van de stikstofproblematiek via een ruimtelijke benadering een hefboom kan zijn voor het aanpakken van andere grote opgaven en zo een nieuw perspectief kan opleveren voor het landelijk gebied. Socio-Environmental Systems Modeling. https://research.wur.nl/en/publications/naar-een-ontspannen-nederland-hoe-het-oplossen-van-de-stikstofpro

Kim, D.-G., & Isaac, M. E. (2022). Nitrogen dynamics in agroforestry systems. A review. Agronomy for Sustainable Development, 42(4), Article 60. https://doi.org/10.1007/s13593-022-00791-7

Laasri, I. (2025). Nutrient recovery strategies and agronomic performance in circular farming: A comprehensive review. Nitrogen, 6(3), Article 80. https://doi.org/10.3390/nitrogen6030080

Lee, C., Fletcher, T. D., & Sun, G. (2009). Nitrogen removal in constructed wetland systems. Engineering in Life Sciences, 9(1), 11–22. https://doi.org/10.1002/elsc.200800049

Legesse, N., Sheng, W., Yao, W., Manqin, G., Peishi, L., Yu, H., Hongjun, X., HongXiang, H., & Youhua, M. (2023). Optimal fertilizer rates towards the improvement of nitrogen use efficiency and reduction of nitrogen export in paddy rice-wheat intensive farming. Frontiers in Environmental Science, 11, Article 1239785. https://doi.org/10.3389/fenvs.2023.1239785

Liu, H., Wrage-Mönnig, N., & Lennartz, B. (2020). Rewetting strategies to reduce nitrous oxide emissions from European peatlands. Communications Earth & Environment, 1, Article 17. https://doi.org/10.1038/s43247-020-00017-2

Malheiro, R., Ansolin, A., Guarnier, C., Fernandes, J., Amorim, M. T., Silva, S. M., & Mateus, R. (2021). The potential of the reed as a regenerative building material—Characterisation of its durability, physical, and thermal performances. Energies, 14(14), 4276. https://doi.org/10.3390/en14144276

Monitor stikstofdepositie in Natura 2000-gebieden 2025 (RIVM-2025-0021). (2025). Rijksinstituut voor Volksgezondheid en Milieu. https://doi.org/10.21945/RIVM-2025-0021

Montes, F., Meinen, R., Dell, C., Rotz, A., Hristov, A. N., Oh, J., Waghorn, G., Gerber, P. J., Henderson, B., Makkar, H. P. S., & Dijkstra, J. (2013). Special topics — Mitigation of methane and nitrous oxide emissions from animal operations: II. A review of manure management mitigation options. Journal of Animal Science, 91(11), 5070–5094. https://doi.org/10.2527/jas.2013-6584

Ndegwa, P. M., Hristov, A. N., Arogo, J., & Sheffield, R. E. (2008). A review of ammonia emission mitigation techniques for concentrated animal feeding operations. Biosystems Engineering, 100(4), 453–469. https://doi.org/10.1016/j.biosystemseng.2008.05.010

OBN Natuurkennis. (2026, 5 februari). Drukfactoren in beeld | Natuurkennis. Natuurkennis. https://natuurkennis.nl/drukfactoren-in-beeld/

Quattrone, G. (2025, 1 september). Documenting the endangered reed architecture of the Iraqi Marshes. ArCHIAM. https://www.archiam.co.uk/documenting-the-endangered-reed-architecture-of-the-iraqi-marshes/

Shepperson, M. (2026). Modern mudhifs: An ancient architectural tradition in a state of rapid change. Journal of Material Cultures in the Muslim World, 6(1–2), 124–141. https://doi.org/10.1163/26666286-12340063

Stikstofdepositie, 1990–2024. (z.d.). Compendium voor de Leefomgeving. https://www.clo.nl/indicatoren/nl018922-stikstofdepositie-1990-2024

Trepel, M., & Palmeri, L. (2002). Quantifying nitrogen retention in surface flow wetlands for environmental planning at the landscape-scale. Ecological Engineering, 19(2), 127–140. https://doi.org/10.1016/S0925-8574(02)00038-1

Urban wetlands | Urban Green-blue Grids. (z.d.). https://urbangreenbluegrids.com/measures/urban-wetlands/

Vymazal, J. (2006). Removal of nutrients in various types of constructed wetlands. Science of the Total Environment, 380(1–3), 48–65. https://doi.org/10.1016/j.scitotenv.2006.09.014

Zak, D., Kronvang, B., Carstensen, M. V., … Kjaergaard, C. (2020). Wetland buffer zones for nitrogen and phosphorus retention: Impacts of soil type, hydrology and vegetation. Science of the Total Environment, 720, Article 137519. https://doi.org/10.1016/j.scitotenv.2020.137519

# Images

Cover: De Kruif, B. (2026). The reed cycle [AI-generated image]. Generated by ChatGPT (OpenAI).

Dorp, P. (z.d.). Onze historie | preHistorisch Dorp. preHistorisch Dorp. https://prehistorischdorp.nl/nl/onze-historie

Een nieuwe kijk op de stikstofaanpak. (z.d.-b). https://ontspannennederland.nl/nieuwe-kijk-op-de-stikstofaanpak

Gaete, J. (2021, 23 april). FaCTs Tåkern Visitor Centre / Wingårdh Arkitektkontor AB. ArchDaily. https://www.archdaily.com/297108/facts-takern-visitor-centre-wingardh-arkitektkontor-ab

Shape — Mudhif: reeds houses – Designed in Iraq. (z.d.). Designed in Iraq. https://designediniraq.org/entry/mudhif-reeds-houses/

Tomati, T. K. F. (2019, 6 april). Wattle and Daub: An Ancient and Simple Natural Building Technique – Mother Earth News. Mother Earth News – The Original Guide To Living Wisely. https://www.motherearthnews.com/sustainable-living/green-homes/wattle-and-daub-ancient-natural-building-zbcz1904/

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