Fællesskabet Landbo

Environmentally sustainable transformation of Danish agricultural buildings and villages

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title page

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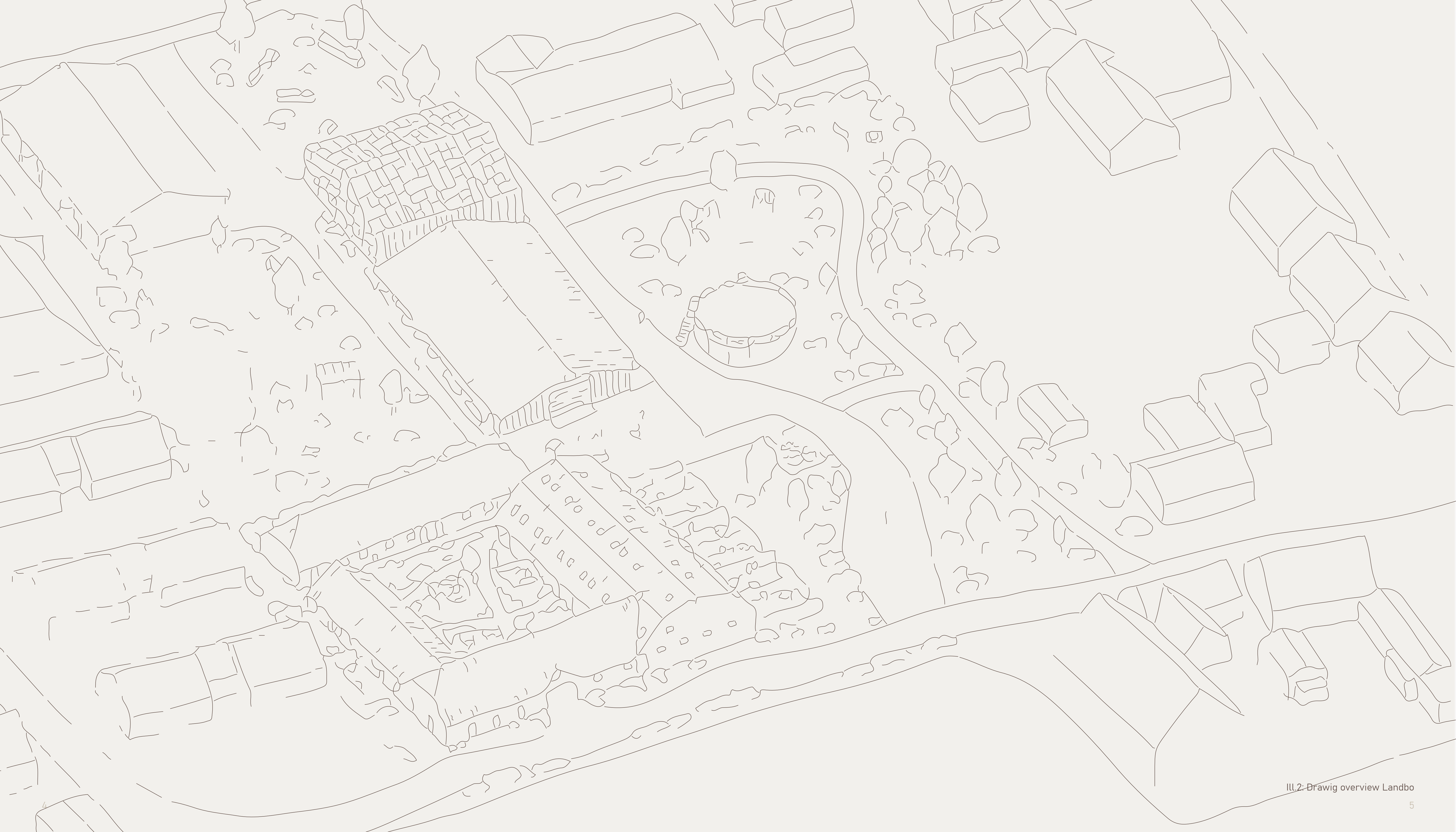
abstract

This thesis explores a socially and environmentally sustainable transformation of a cattle farm located in Råby through various architectural and engineering methodologies and analyses within the integrated design process. The transformation examines the cultural and historical significance of farming throughout the years, and how the rural landscape has been developed as a result of this. Assisted by a life cycle assessment approach, an investigation of the concept of housing rotation was conducted, where two scenarios of resident movement patterns within a village like Råby illustrated the potential to reduce the climate footprint through the implementation of this concept. Several site analyses, design and literature studies have informed the thesis, which concludes with a design proposal for the transformation of the cattle farm, called *Fællesskabet Landbo*, where the concept of housing rotation has been integrated. *Fællesskabet Landbo* is a community-based housing association which offers dwellings and new functions to the city of Råby.

Ill.1: Render window



Ill.2: Drawig overview Landbo

content

Ill.3: Drawing courtyard

prologue

Reading guide | Introduction | Method

Ill.4: Render window

reading guide

This thesis report is structured into several chapters that collectively outline the project's foundation, development, and final outcome. It begins with a brief introduction to the central problems addressed in the project. This is followed by an overview of the theoretical framework and analyses that have informed the final design, alongside an examination of the project's site and context.

The final design proposal is then presented through a range of visualisations and drawings. This is followed by a detailed exposition of the design process, highlighting key considerations and iterations. The report concludes with a discussion, conclusion, and critical reflection, offering a broader perspective on the project, its development, and its outcomes.

This structure has been chosen to provide the reader with an initial overview of the final solution, after which the underlying arguments and design considerations are presented as supporting material.

introduction

Across Denmark, agricultural activity is in decline, and an increasing number of farms are closing due to various structural and economic changes (Danmarks Statistik, 2024). As a result, the number of empty farms is growing nationwide (ill. 5).

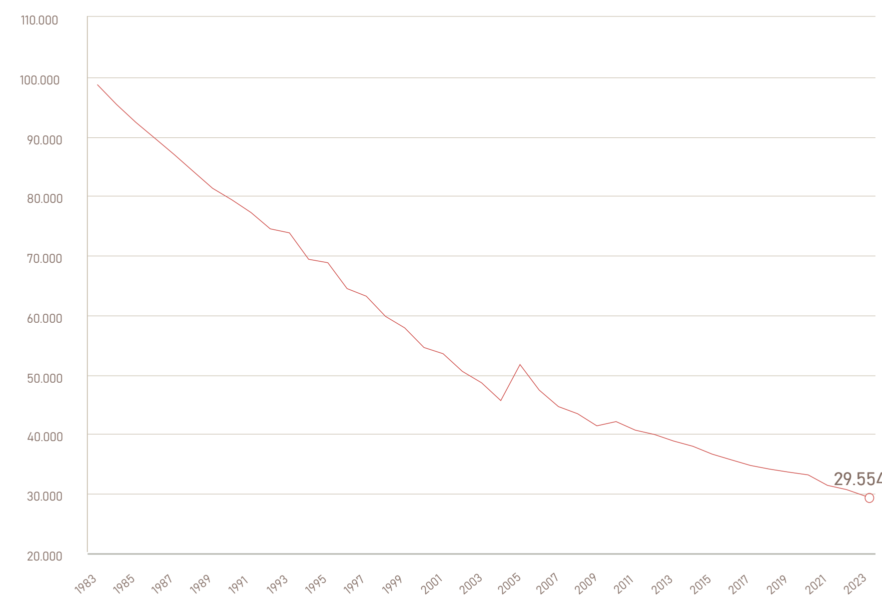
In 2024, Randers municipality issued an idea competition "It's so lovely in the countryside" (Danish: Det er dejligt på landet). The purpose of the idea competition was to encourage new, innovative and sustainable transformation suggestions for these empty farms to create new life and synergy to the villages in the rural land. (Randers Kommune,2024).

For this thesis, a cattle farm located in Råby was selected as a case study for transformation, based on recommendations from Randers Municipality. The chosen farm is a family-owned property with roots dating back to the 1800s, historically engaged in both crop cultivation and livestock breeding. Today, it functions as a cattle farm managed by a single farmer who inherited it from his father.

The objective of this thesis is to develop a sustainable design proposal that emphasises the qualities of the farm as a cultural-historical element while accommodating the surrounding village. By implementing circular strategies, like housing rotation, that supports the development and growth of Råby though an environmental and social sustainable based transformation ensures the Danish village's ability to thrive and sustain a relevant future.

A study of the village residents' moving patterns, utilizing a life cycle assessment methodology, is conducted to investigate and evaluate the climate footprint of implementing housing rotation in Danish villages. Finally, a design solution is derived from the findings of the studies, analyses, and investigations of the cattle farm, forming the housing association called *Fælleksskabet Landbo.*

Agricultural and horticultural holdings



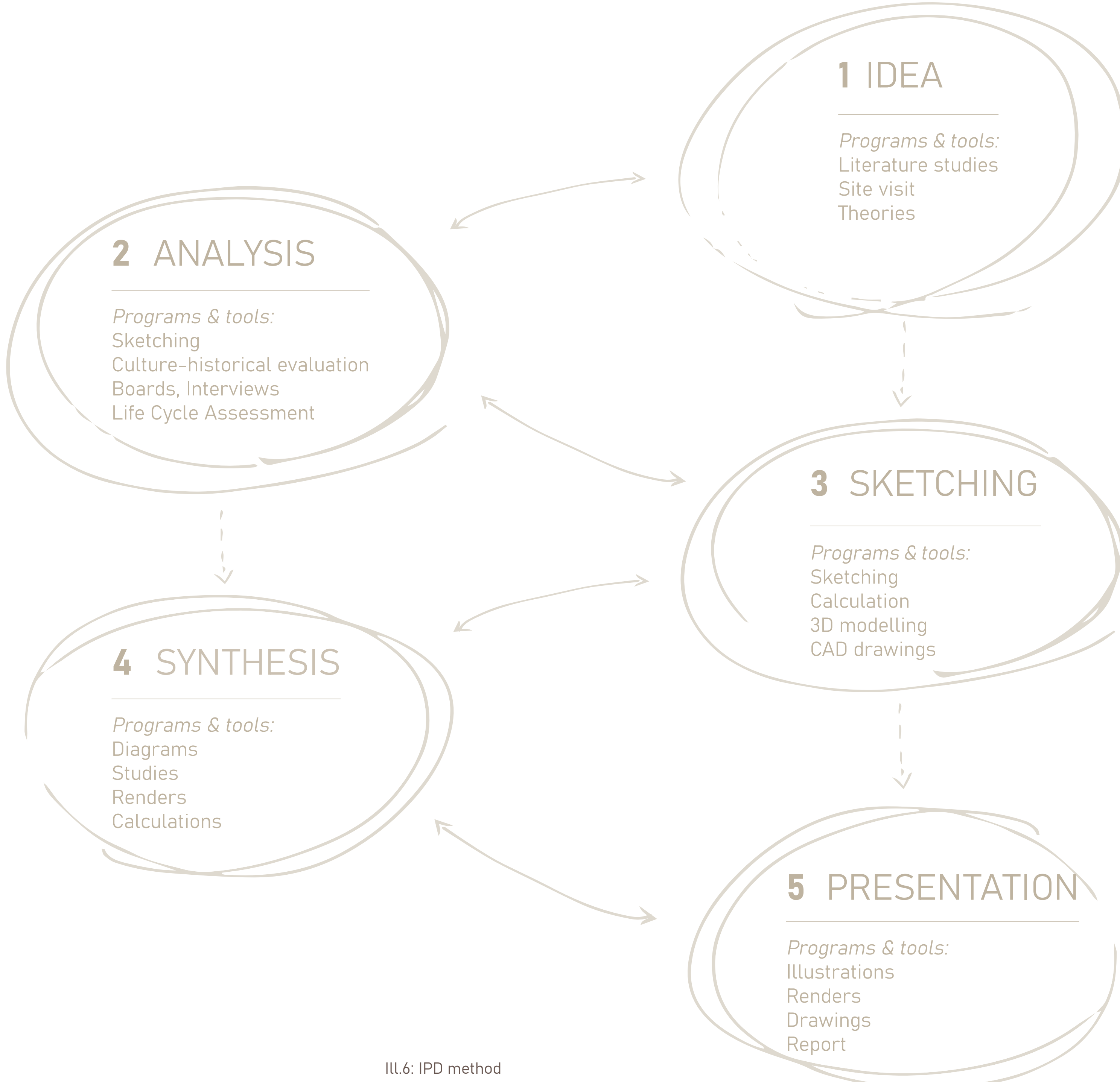
Ill.5: Agricultural and horticultural holdings (Danmarks Statistik (2024))

method

For this thesis, the methodology utilised is the iterative approach of the Integrated Design Process formulated by Mary-Ann Knudstrup and Hanne Trine Ring Hansen (Hansen, H.T.R. and Knudstrup, M.-A. (2015)). The methodology has been introduced and favoured in the education at Aalborg University's architecture and design programme, due to its ability to ensure a holistic design outcome, where architectural and engineering knowledge are combined. For this section, the phases of the methodology will be explained through the thesis' take on each of the phases.

The analysis phase mainly consisted of understanding the site and its conditions. Mostly, traditional architectural site analysis was conducted in the beginning of the project, along with specific investigations of users' demographics and examinations of housing rotation through life cycle assessments and energy estimations. Later in the project, more design-focused studies and examinations were conducted as the project developed.

In the synthesis phase, the sketches and considerations from the previous phases were gathered and defined into a design solution. Different investigations and examinations had been conducted and provided knowledge and understanding of various aspects of the existing building masses and site, which came together and supported the overall design solution. Going back and forth between the synthesis phase, the sketching phase, and the analysis phase evolved the project and design solution, ensuring a holistic, integrated architectural- and engineering design outcome.

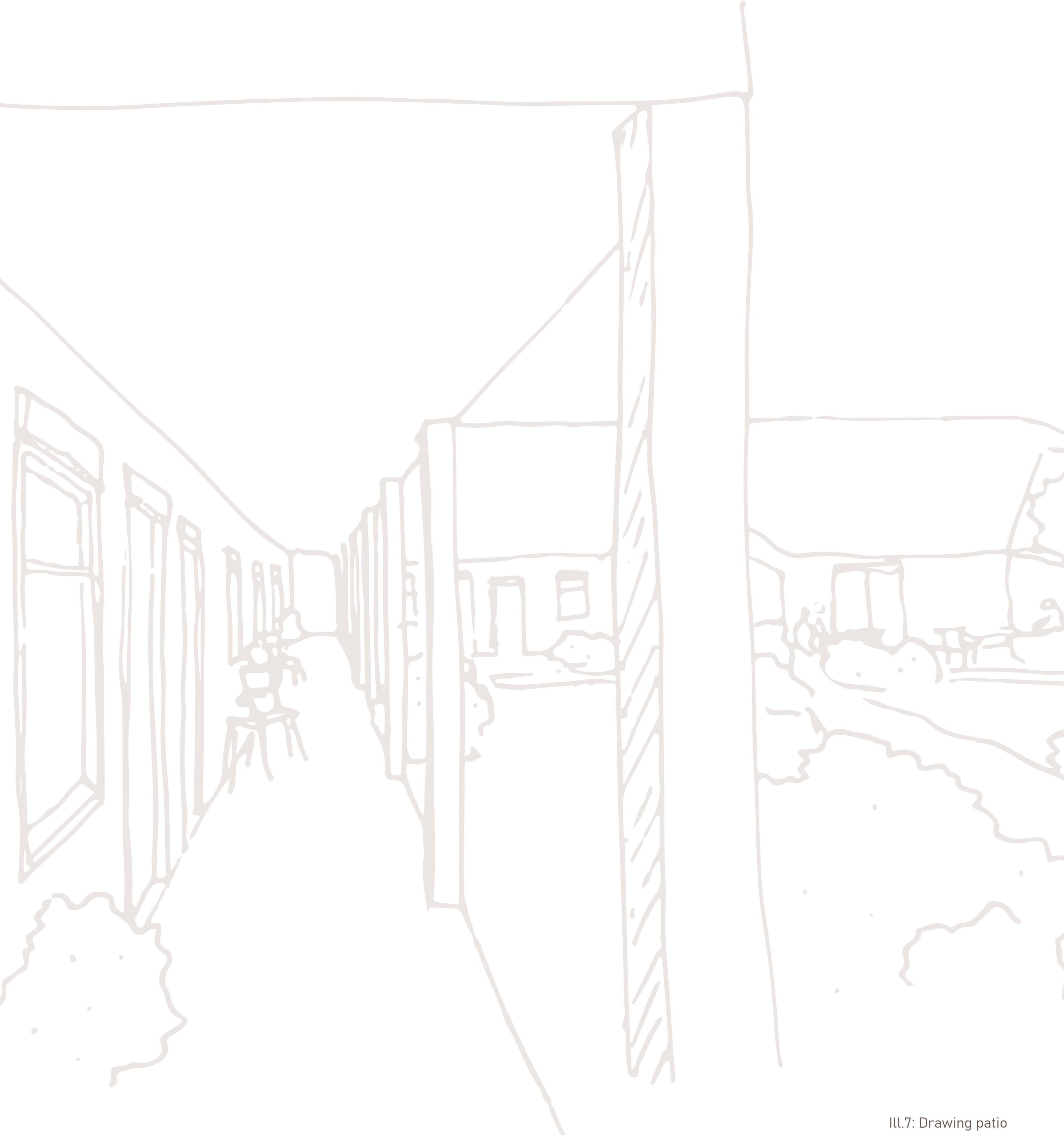


Ill.6: IPD method

In the idea phase, the thesis' basis was formulated through different literature studies, along with site visits and discussions. In this part of the project, the problem statement was created, supported by different theories and analyses. Going back and forth between the idea and analysis phase provided an iterative workflow that ensured a well-informed foundation for the project.

In the sketching phase, all the information and knowledge provided from the previous phases came together in illustrative forms, which truly marked the beginning of the design phase of the project. Sketching was articulated in different media, such as hand- and CAD drawings, along with 3D modelling. This approach to designing with different media made it possible to examine and develop design solutions at different scales and for specific areas of the site.

The final phase, the presentation phase, gathered all the learnings from the project and formulated and visualised the design solution in the form of drawings and visualisations, along with a report. The report is a communication tool, where the presentation and the process behind it, along with the methodology, are conveyed.



Ill.7: Drawing patio

theories & thematics

Transformation | History of Danish farms

Circular sustainability | Housing rotation

Life cycle assessment | Adaptability

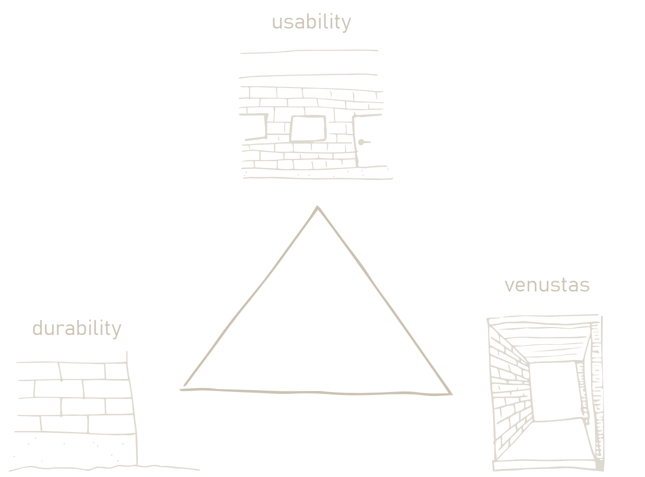
The following section will introduce a range of topics and theories relevant to the project. Each of these theoretical frameworks has played a crucial role in informing both the design process and the final outcome. The section will provide an overview of the key theoretical principles, highlighting how the knowledge and insights derived from these theories have shaped the design approach. Furthermore, these theories will be revisited and applied throughout the report.

transformation

A fundamental and classic approach to architecture is Vitruvius' definition, which emphasises three main principles: firmitas (durability), utilitas (usability), and venustas (beauty) (Dansk Arkitektur Center, 2025). In the context of modern architectural language, these principles can be interpreted as technical (firmitas), functional (utilitas), and aesthetic (venustas). These elements are essential to architectural design and must be carefully considered and integrated into a project. However, when working with transformations, these principles can be applied in alternative ways.

When working with existing buildings, the history and context must be examined to gain an understanding of the original intentions behind the building masses and to explore the new potentials they may offer for future uses. There are various architectural approaches to transformation, both in theory and practice.

Technic-historic & phenomenal basis is an approach to architectural transformation formulated by Nicolai Bo Andersen, MAA (Andersen, Nicolai B. (n.d.)). The three bases form equally important aspects of understanding the existing building. The historical basis concerns the building's historical background, while the phenomenological basis focuses on examining the masses in a sensory way. Lastly, the technical basis examines the physical connections within the construction. These three aspects must be considered during the analysis and sketching phases in order to develop a comprehensive design that emphasises the existing elements.



Ill.8: Diagram Vitruvius

For the technical basis, the existing buildings of the cattle farm will be analysed in terms of building materials and functionality to determine what new functions the buildings can accommodate through the transformation. This will be done alongside investigating and integrating principles of circularity as a sustainable approach to the transformation.

Understanding the site and context through phenomenological analysis, such as serial vision, will be conducted, while the investigation of the historical context will involve an exploration of the historical development of farming culture and the associated buildings. A SAVE analysis will provide insight into the historical significance of the existing buildings to assist in determining their preservation value and functional relevance.

history of *Danish farms*

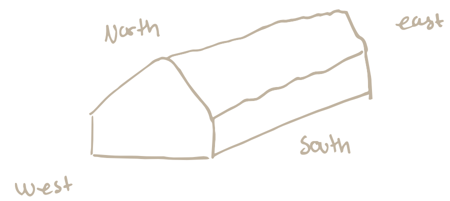
To gain an understanding of the development and history of Danish farms, a study of the farm's physical changes in a historical context will be conducted in this section, as outlined in the previous section. This will help identify the characteristics of the cattle farm in the later SAVE analysis (see page 46), along with understanding the importance of preserving its elements.

Throughout the years, several agricultural changes and reforms have shaped the farms and the rural landscape. In 3900 B.C., the principle of longhouses was introduced in the rural areas, allowing farmers to shelter themselves from the weather and wind. The rectangular house was oriented in the landscape with the long sides facing north and south to gain passive heat and shelter from the western wind (Lauring, M., 2022).

Another notable reform was the lot substitution of the 19th century, which led to a significant rotation of the rural land. Originally, farms were clustered together in villages, where a community of cultivation flourished. The new reform provided farmers with plots of land that were placed together, optimising workflow. However, this also meant that farm buildings were relocated from the village to more isolated plots in the rural landscape. As a result, the previous village community built around the farms disappeared (Bavnshøj, P. et al., 2004).

In 1853, Copenhagen's agricultural college was founded, marking the knowledge-based development of the farming industry. Along with this, new cultivation methods and tools were invented (Realdania, et al., 2016). This optimised the workflow on farms and increased the production, which is evident in the architecture. Fine detailing, decorative cornices, and brick elements highlighting both the windows and entrance openings were dominant in the brick facades of the buildings. The architectural expression was inspired by bourgeois houses in the city, built in a historicist style (Realdania, et al., 2016).

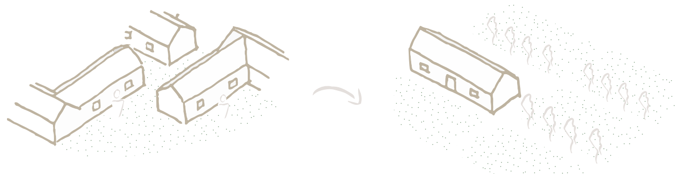
3900 B.C.



1780

By the end of the 1800s, major reforms were implemented to modernise the agricultural land. Previously, the agricultural land had been dominated by the aristocracy. However, in 1788, the rule of serfdom was revoked, yet the rural land was still primarily owned by the upper class and aristocracy. To ensure the survival of rural land not owned or controlled by the upper class, another reform was introduced in 1790. This reform prohibited the demolition of existing farms unless new ones were established. This ensured the survival of a thriving community of people who remained, which resulted in a transfer of ownership from the aristocrats to common people (Bavnshøj, P. (2004)).

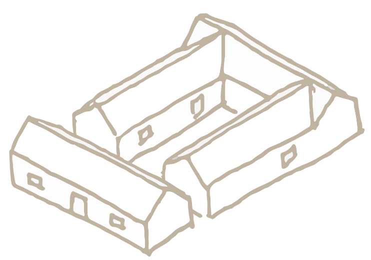
1800



1830

In 1830 the agricultural business boomed, driven by high export of grain. This provided an expansion of farm buildings. The dominant type of farm buildings was the wing-farm-typology. (Realdania, et al. (2016)). A rectangular building mass with saddle roof, combined with other buildings, most-likely two or three other, enclosing a central courtyard and forming the winged farm.

1853



The farm in
1800-1850

Four wing farms:
One living wing along with three connected barn wings.

Typical 6-8 m deep
Long facades, short gables

Risen popularity of bricks

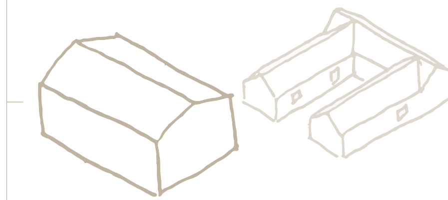
By the end of the 19th century, more farmers became organised in cooperative movements, which were economic collaborations that distributed production and provided better terms for individual farmers (Bjørn, C., 2024).

The barns in
1850-1900

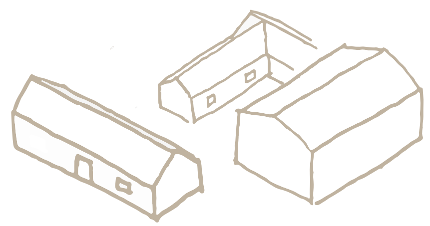
Stables are disconnecting the living wing

Stables and barns are becoming larger

Size and openings fit the technological development



In 1935, around the beginning of the Second World War, building practices had changed. More installation possibilities emerged, and technical elements such as electric lighting, water, and heating were slowly integrated into the farms, ensuring a more comfortable way of living (Realdania, et al., 2016).



The farm in
1900-1950

The living wing are of the same standard as townhouses

More specified buildings

A rational approach towards the stables and barns' functionality

In 1973, the year Denmark entered the European Union, the agricultural market was transformed. Suddenly, Danish farmers became players in the European market, which brought both more opportunities and increased competition. The need for more specialised farms and mass production further changed the farming industry and the rural landscape (Cohen, Marshall H., 1986).

1900

In the early 20th century, grain production declined, and more farms invested in livestock and breeding operations. Along with the rise of information and technical developments, a new awareness of hygiene emerged, resulting in a rethinking of the farm's structure (Realdania, et al., 2016). The animal stables grew larger and were moved further away from the living wing of the farm (Kulturarvsstyrelsen, n.d.).

1935

1945

Around 1945, the rationalisation and mechanisation of the farming industry began. A simpler and more symmetrical architectural expression emerged, suggested by Bedre Byggeskik (English: better building practice), a building guide based on Danish building tradition that ensured good craftsmanship and higher building standards.

The industrialisation and mechanical development of Danish farms occurred at a slow pace. From 1950 to 1965, it was mainly a period of renovation and transformation, during which existing barns and stables were modified to accommodate new functions (Realdania, et al., 2016).

1973

today

Ill.9: Timeline

circular sustainability

In architecture, there are various approaches to sustainability. In this section, the topics of sustainability that the thesis will address are explored. There are three main aspects of sustainability in general: social, environmental, and economic sustainability. The latter will not be included in this paper.

Social sustainability concerns people's well-being, with social justice and welfare at its core. The individual's needs are prioritised, and inclusive elements that consider various challenges are integrated into the design. In this thesis, elements that ensure individual satisfaction are considered through representative users (see p. 51) (Danske Arkitektvirksomheder, 2025).

Besides social sustainability, environmental sustainability is a key element of this project. The building industry has a high climate footprint, and various initiatives and efforts are underway to reduce this (Nielsen, S. & Guldager Jensen, K., 2024). When it comes to environmentally sustainable building practices, the concept of circularity plays an important role. Implementing circularity across different aspects of architectural design, construction, and social use helps ensure a building's long-lasting relevance and extended lifetime. The three aspects of circularity present different aspects to be applied in the project (Nielsen, S. & Jensen, K. G., 2024).

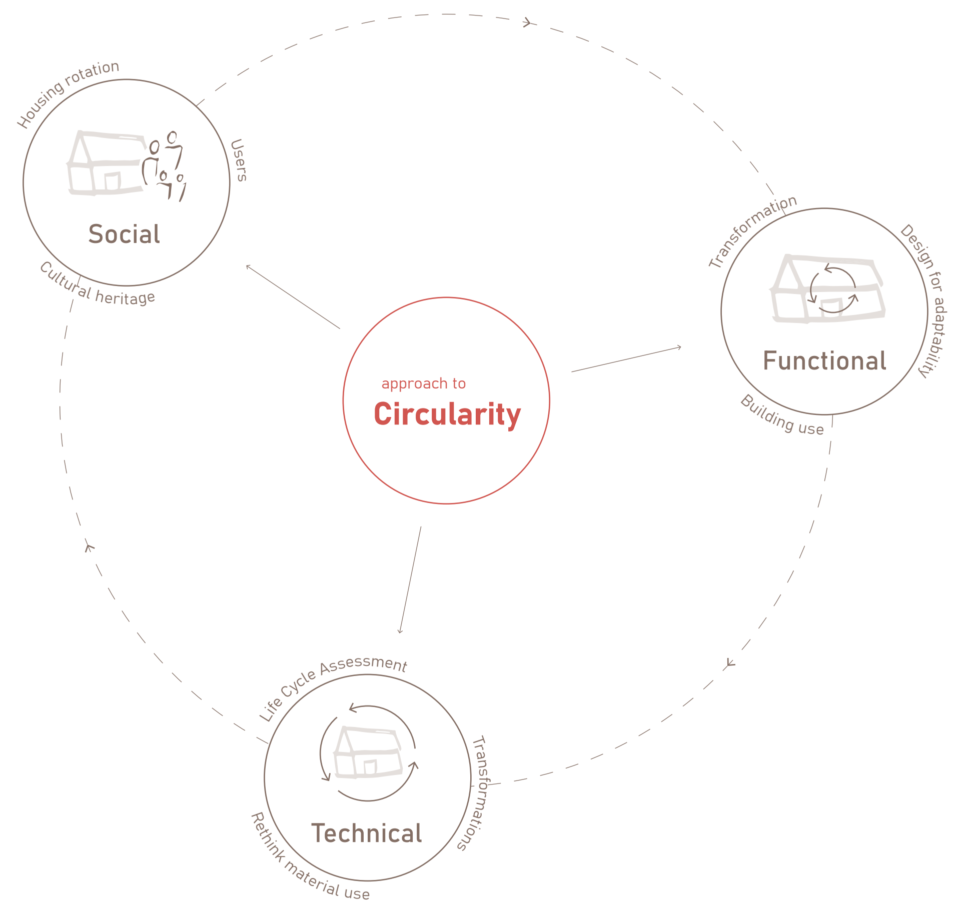
The social aspect of circularity emphasises the importance of creating a high quality of life for the users of the building. An understanding of the social context is essential to define the users and their needs. In small rural towns, the village structure and local community play a significant role in the social context.

To support social development in these areas, the principle of housing rotation will be investigated, where the possibility for various dwelling types within a village provides social relevance and diversity. See page 24 for further explanation (Nielsen, S. & Jensen, K. G., 2024).

The functional aspect concerns creating volumes and spaces that allow for adaptability. Transforming with the principle of adaptable floor plans will ensure future transformation opportunities and the ability to adjust to the evolving needs of users. It is important to understand the current relevance of the building's use and functions, as well as the potential they may offer in the future (Nielsen, S. & Jensen, K. G., 2024).

The technical aspect of circularity concerns the rethinking of materials. The implementation of life cycle assessment helps achieve lower carbon emissions in construction. Rethinking material use can ensure a material's new use and purpose, thereby extending its lifetime (Nielsen, S. & Jensen, K. G., 2024). Another strategy for reducing carbon emissions is to favour biobased materials, which store CO_2 during the production phase and contribute to lowering the overall climate footprint.

By using this approach to circularity and sustainability as the foundation for the project, long-lasting buildings with continued social relevance and physical adaptability to future needs can be achieved. The three principles of circularity will be elaborated in the following sections to specify the approach and their application.



Ill.10:Diagram circularity

housing rotation

To investigate the social circularity aspect, the concept of housing rotation is explored. Housing rotation is a sustainable relocation process that ensures housing opportunities for all types of residents within established villages (Forening for Byggeriets Samfundsansvar og Landdistrikternes Fællesråd, 2024).

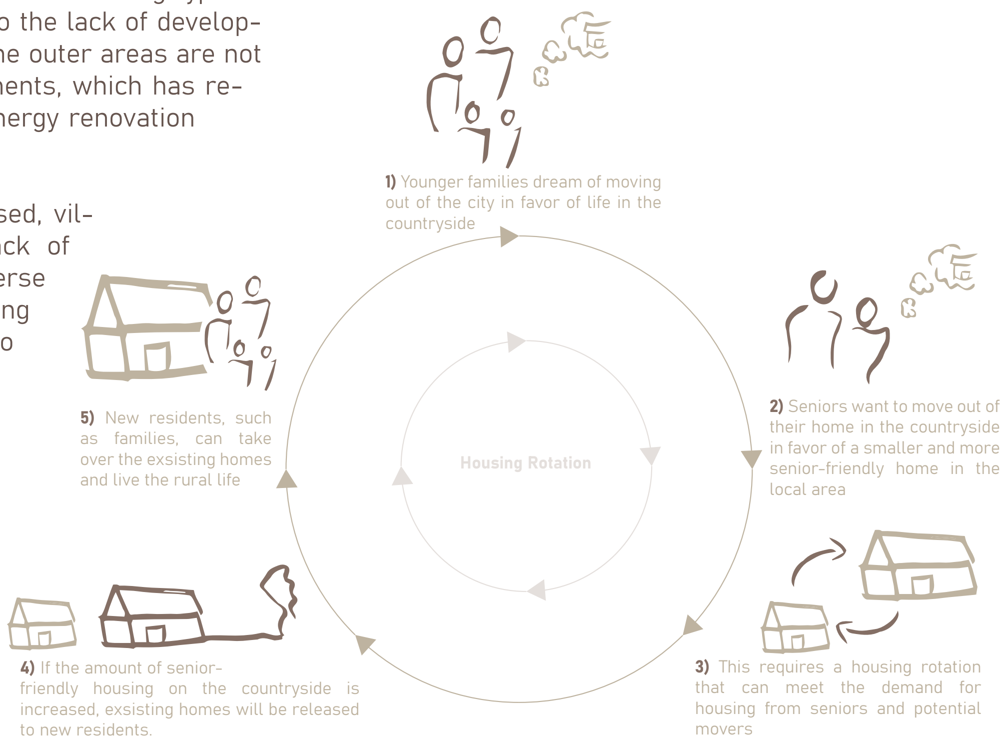
Housing rotation occurs when existing homes become available as older local residents wish to move into smaller housing. This creates space for new residents who desire to move to the villages. The rotation provides an opportunity for these new residents to renovate and adapt the existing homes to modern standards.

Over time, two fundamental issues have occurred in the villages. Firstly, the amount of diverse housing typologies is almost non-existent due to the lack of development. Secondly, many homes in the outer areas are not adapted to meet today's requirements, which has resulted in a significant need for energy renovation of existing housing.

If these issues remain unaddressed, villages nationwide will face a lack of development. The lack of diverse housing typologies makes housing rotation stationary, as there is no replacement of residents in the villages.

As a result, the average age of the population in villages continues to rise. Therefore, the implementation of a housing rotation strategy will help ensure a growing community and make villages more diverse and sustainable.

In this project, the transformation of a cattle farm in Råby will investigate the concept of housing rotation from a technical perspective. The climate footprint of the rotation and the residents will be examined through a life cycle assessment methodology (see p. 59) to define the environmentally sustainable impact housing rotation will have on villages in the rural land.



Ill.11: Diagram housing rotation

life cycle assessment

To establish an approach to life cycle assessment (LCA) in relation to the concept of circularity and housing rotation, this section will explore the principles of LCA.

With today's environmental challenges, where buildings play a significant role in the pollution of greenhouse gas emissions, there is an increasing focus on reducing this impact. LCA is a tool used by designers and building developers to assess a building's carbon footprint. In general, the LCA evaluates different stages of a material's life cycle, which are: A) Production, B) Use, C) End of life, D) Beyond (Nielsen, S. & Jensen, K. G., 2024).

The goal of this project, as described earlier, is to transform a cattle farm in Råby. Since the transformation focuses on repurposing the existing buildings and reusing a large amount of the current materials, the need for additional new building products is reduced.

For the LCA investigations throughout the report, the following stages will be utilized: **Stage A** defines the carbon emissions of the different building materials throughout their production, transportation, and manufacturing. **Stage B** addresses the product's usage phase, where replacements of the materials and the operational energy use of the building are defined. **Stage C** is the end-of-life stage of the material, where waste processing and disposal are specified. Lastly, **Stage D** examines the potential for reusing building materials in a new cycle (Nielsen, S. & Jensen, K. G., 2024). However, this stage is excluded from the calculations due to the uncertainty surrounding the reuse of building materials at the building's end-of-life stage.

Besides reusing materials through transformation, investigations of biobased materials will also be included in the further design process. Biobased materials provide an advantage in LCA investigations due to their ability to absorb and store carbon, ensuring a low or negative carbon footprint when utilised in Stage A of the LCA (Kanafani, K., 2024).

Additionally, in this thesis, another approach to LCA has been incorporated through the concept of housing rotation. This report seeks to investigate the climate footprint of housing rotation through the application of LCA. In doing so, a more sustainable and holistic approach to reducing buildings' greenhouse gas emissions can be achieved.

adaptability

In relation to the functional aspects of circularity, adaptability will be investigated to ensure a long-lasting design that is flexible for future changes or needs. This will support the design process of transforming the cattle farm's buildings and layout.

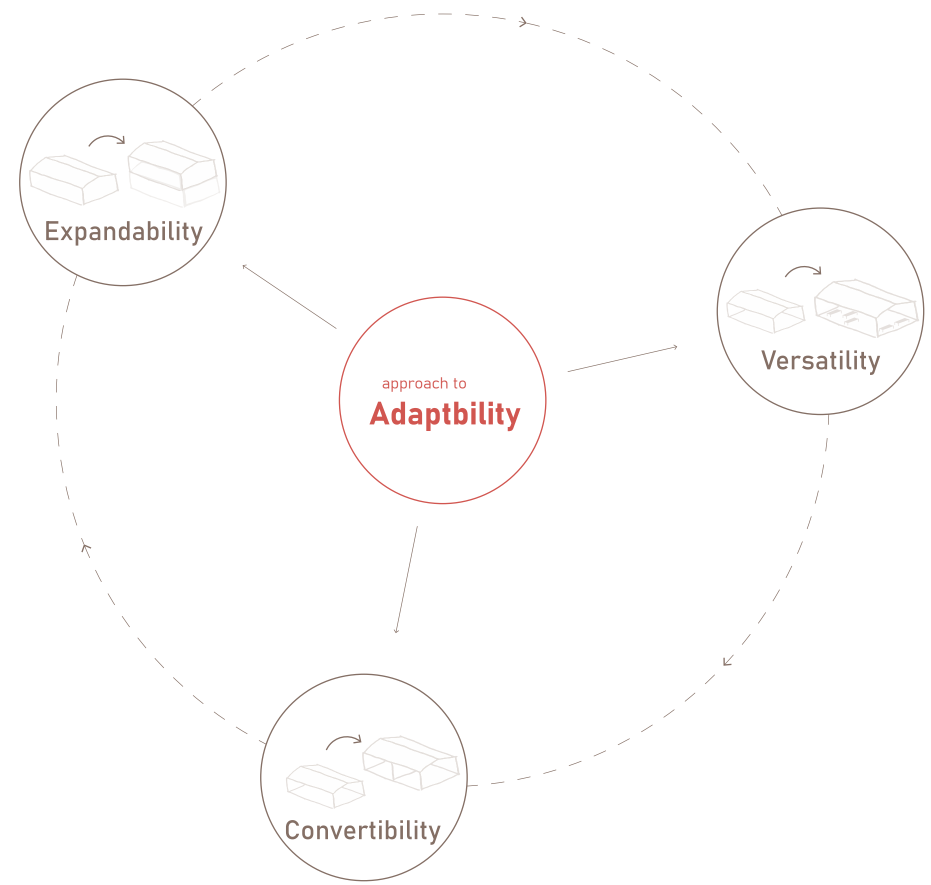
Adaptability, in correlation with circularity, implies the changes of functional spaces within a building when new needs or expectations arise. Over time, people experience changes in living status, where the needs for one's dwelling may no longer meet a certain standard, or the dwelling itself may exceed the user's necessities. Designing for adaptability will therefore ensure a flexible housing layout that can adapt to the user's changing demands. The project will include specific transformational design modifications within the building, that consider the resident's changing needs. There are three design levels of specified adaptability, these are versatility, convertibility and expandability. (Dansk Standard, 2020).

The objective of versatility is designing for spatial variety with minor interior changes to accommodate various functions. This approach suggests that spaces must ensure a level of flexibility that allows for changing the original function to new functions or activities.

Convertibility, on the other hand, is a more interventional approach, where structural elements can change the spatial functions or activities. This type of adaptability is suited for long-term changes, as it is a more difficult operation. Designing for convertibility allows interior elements, such as walls, partitions, and other elements that are not part of the bearing structural framework, to be adaptable in order to change the spatial functionality.

Finally, expandability is the largest intervention in terms of building adaptability. Designing for expandability seeks to expand the building's floor area, whether horizontally or vertically. This approach accommodates substantial change, where new spaces are created to increase the overall floor space. (Dansk Standard (2020)).

The aim of this project is to use the first two levels of the adaptability approaches in the design of the cattle farm.



Ill.12: Diagram adaptability

Ill.13: Drawing terrace

site investigations

Råby | City history | Building structure | Green structure |

Serial vision | State of the Art | Facades studies | SAVE

Building on the theoretical foundation of transformational approaches—examining both historical context and the circular sustainability framework—this section investigates the city of Råby and its site location. It begins with an introduction to the city, followed by a cultural-historical overview of its development. Subsequently, a series of site analyses, based on both observations and desktop research, are presented and assessed. The aim is to develop a comprehensive understanding of the site and its surroundings within an architectural and urban context, thereby providing a foundation of essential insights to inform and support the design process.

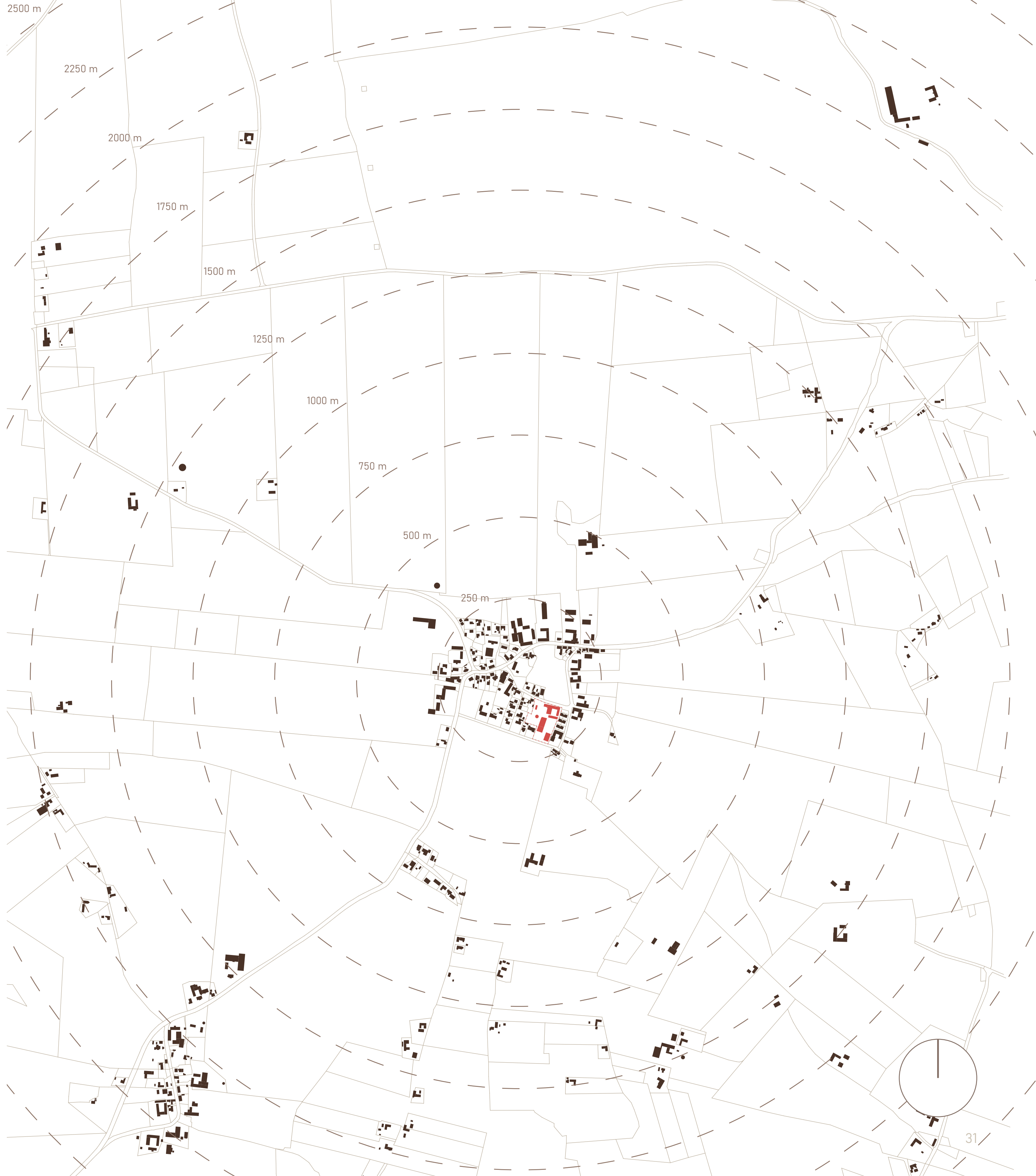
Råby

As stated in the introduction, the cattle farm is located within the village of Råby, a small settlement situated in the central region of Jutland, Denmark, specifically in the northeastern part of Randers Municipality.

As seen in Illustration 14, Råby appears as an isolated village surrounded by open fields and natural landscapes, with a significant distance from nearby urban structures. Råby is known for its large village pond, located at the centre of the village, which contributes to the perception of openness in the townscape (Randers Kommune, n.d.). The project site is located at the southeastern edge of the village and is marked in red.

The Municipality of Randers has a strong interest in developing its villages in the rural districts. It sees potential in improving the local community and preserving cultural heritage to strengthen the identities of local settlements (Appendix 01: Planning Conditions). To emphasise this, an investigation of Råby as a cultural environment (Appendix 02: Cultural environment) has shown that Råby possesses both cultural and historical identity worth preserving.

The next section will present further investigations supporting the above, including Råby's history, along with additional analysis of the village's structure and site conditions.



Ill.14: Råby 1:5000

city history

To gain a deeper understanding of Råby's potential and qualities, a historical investigation has been conducted, building upon knowledge from the previous section on farming history (see page 19).

The earliest recorded mention of the village dates back to 1428 as 'Roghæby', a name inspired by its placement on a small hill in the landscape, as 'roge' in Danish means 'pile' (Randers Kommune, 2011, p. 2).

During the Late Middle Ages, the village functioned as a 'forte' village (Randers Kommune, 2011), characterised by a circular layout of farms surrounding a centrally placed green area (see Ill. 15). The green area, known as the 'forte', was used by the farmers for gathering cattle and hosting markets for the village residents (Randers Kommune, n.d.). The church, located in the southeastern corner of the village, was originally established around the year 1550, at the end of the Late Middle Ages (Randers Kommune, 2011). Due to the lot substitution of the 19th century, several farms were relocated away from the village, rendering the function of the 'forte' redundant. It subsequently became an excavation site for clay extraction (Randers Kommune, n.d.).

In the first half of the 19th century, the remains of the 'forte' were excavated and transformed into a village pond (see Ill. 16), which became a dominant element in the village centre (Randers Kommune, n.d.). Farmers used the pond as a water source for their cattle, and it later served as the village's water supply and fire pond (Det Danske Sprog- og Litteraturselskab, n.d.). Some of the surrounding farms were removed and replaced by new typologies, such as smaller single-family homes. Råby's local hall was constructed in 1898, providing an opportunity for the local community to have a common meeting place (Randers Kommune, n.d.).

After the year 1900, the village expanded westward, primarily adding single-family houses. As Råby grew, a school and a missionary house were also established (Randers Kommune, 2011).

Today, Råby remains a small village, which, according to a parish report, states that the Råby parish houses 436 residents (Kirkestatistik, 2024). Over the years, the village has undergone several changes, with some farms being replaced by new single-family houses in the southern part (Ill. 17) (Randers Kommune, 2011). The school and the missionary house have been closed, but the local hall remains an active part of the village. The village pond no longer serves a practical purpose but holds historical value and appears as an attractive element in the city's image. Covering a 15,000 sqm water surface (Randers Kommune, n.d.), it is the largest village pond in Northern Europe. Since the pond is of great importance to the city, it has undergone renovation and maintenance to ensure its preservation (Pedersen, Karin Hede, 2009).

It has been clarified that, despite its small size, Råby boasts a rich historical heritage dating back to the Late Middle Ages. Although the village structure and the 'forte' have evolved over the centuries, distinct traces of the village's original layout remain, particularly through the still-standing farms surrounding the village pond. Throughout its history, Råby has functioned as a farming community with a strong focus on developing the local area. This aligns well with the objectives of this project, which seeks to enhance Råby's heritage by preserving one of its old farms and transforming it into a new, community-focused typology.

Ill.15: Råby 1819

Råby 1819

- Strong emphasis on agriculture
- Central green area for cattle
- Farms encircling the central green area
- Village surrounded by fields

Ill.16: Råby 1900-1940

Råby 1900-1940

- Some farms replaced by new typologies
- Circular village structure preserved
- Central pond replaces the green area
- Village are still surrounded by fields

Ill.17: Råby today

Råby today

- Village expanded with additional dwellings
- More diverse building typologies
- Some farms still preserved around the pond
- Village pond remains a strong identity in the village

building structure

An analysis of Råby's built environment and typologies is conducted to gain a deeper understanding of the village's structure.

The map (ill. 18) illustrates the various building typologies in Råby. The village is primarily composed of single-family houses and wing-farms, which feature large barns for storage and utility purposes. Nearly every single-family house is accompanied by additional structures, such as sheds, garages, annexes, or barns, providing extra storage and living space for residents. There are very few townhouses developed in Råby. Additionally, the village contains a limited number of commercial businesses.

A more specific analysis of the different typologies and built areas in Råby reveals that the village generally contain a low utilisation of building plot area (see scheme below). The scheme presents the various typologies, indicating the corresponding building plot sizes, built areas, plot ratios, and years of construction, with values ranging from lowest to highest.

The farms significantly contribute to the low utilisation of building plot area, exhibiting a low plot ratio due to the large expanses of rural land they occupy, despite having substantial barns. The single-family houses, on the other hand, show a range of plot ratios, from minimal to relatively high, depending on the size of the houses. The inclusion of additional structures such as sheds, garages, annexes, and barns further increases their built area. The few townhouses present in the village generally contribute to denser dwelling patterns on smaller building plots.

As described earlier, this study shows that Råby generally consists of single-family houses and large wing-farms. The utilisation of built area is very low in the village due to the large amount of undeveloped rural land. By incorporating typologies such as row houses in the transformation of the cattle farm, it will ensure more compact dwellings, along with public housing opportunities that promote housing rotation and greater diversity among the residents of Råby.

	Quantity number	Building plot sqm	Building area sqm	Plot ratio percent	Year of construction number
Farms	13	5764 - 289.482	-	0,28 - 22,22	-
Farmhouse	13	-	135 - 359	-	1886 - 1980
Barns	11	-	250 - 1968	-	1884 - 2000
Single family house	74	255 - 3.793	-	5,69 - 51,61	-
House	74	-	32 - 455	-	1830 - 1995
Shed/garage/annex	64	-	14 - 312	-	1890 - 2018
Barns	3	-	197 - 553	-	1903 - 1977
Town-house	8	206 - 558	65 - 89	23,28 - 40,29	1988 - 1989
Shed	6	-	8	-	1988
Occupation	4	667 - 950	60 - 501	12,79 - 87,79	1900 - 1971
Total	99	1.056.792	34.356	3,25	1830 - 2018

Ill.18: Building structure 1:5000

green structure

With the village pond located at the centre of Råby, its dominance in the urban landscape is visually reinforced by the surrounding built environment. The pond improves the quality of the urban space and fosters an open layout between the buildings. Beyond the village egde, kilometres of agricultural fields stretch into the landscape (Appendix 03: City image)

Given the site's location within these open fields, a microclimate analysis (Appendix 04: Micro climate) was conducted. A dominant western wind must be taken into account in the planning and design of the project site.

It is essential to note the terrain's contour lines, which illustrate the undulating landscape of the fields. These must be incorporated into the design of the cattle farm, as well as the changing landscape outside the city. In the serial vision analysis, these elements will be emphasised in a phenomenological exposition.

Ill.19: Green structure 1:5000

serial visions

The serial vision follows a route around the village pond in Råby and continues into the cattle farm. The key insight from the phenomenological analysis is the sense of openness that the pond provides to the village. Due to its shape, the circulation around the pond is organic, creating subtle twists that make the path a space for spontaneous encounters. The path is not only for pedestrians but also for cars, which occasionally create conflicts in the flow. Throughout the walk, visibility of the pond is often blocked by houses placed directly along the water's edge, interrupting the visual connection between the village and the pond. Overall, Råby is a quiet village with a remarkable pond that has shaped the village's appearance and circulation.

Entering the cattle farm through the entrance port, a tunnel-like experience briefly reduces the natural daylight. The route continues into the courtyard, enclosed by a four-winged building structure covered in gravel. From there, the path moves into the more industrial part of the farm, including the slurry tank and various barns. Here, the building density decreases, creating a more open space. Moving from the northern end of the site towards the south, one encounters a rising slope. At its peak, the slope begins to descend again towards the south. This physical change in terrain creates distinct zones within the site. The northern and southern sides of the site lack a visual connection due to the terrain change, which must be addressed.

Ill.20: Serial vision I, own picture

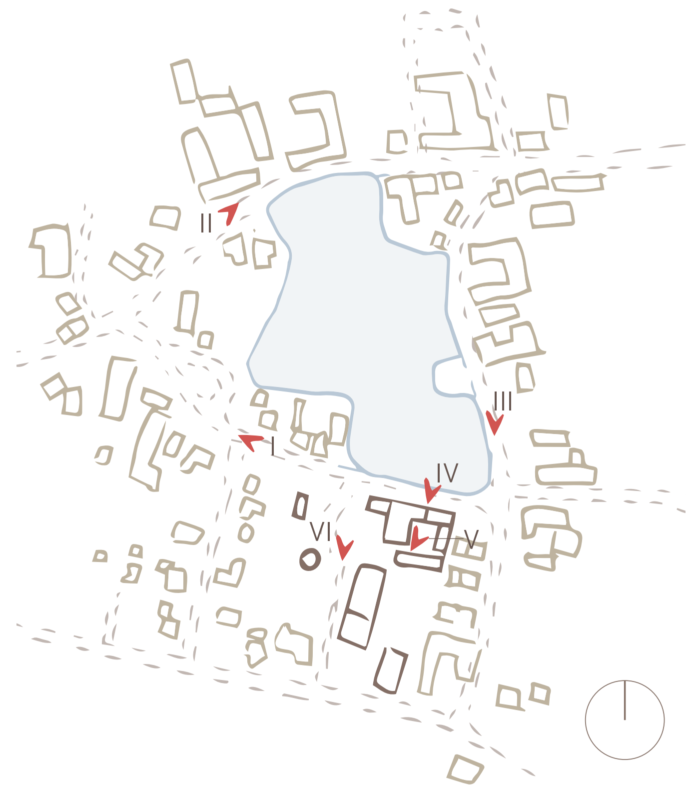
Ill.21: Serial vision II, own picture

Ill.22: Serial vision III, own picture

Ill.23: Serial vision IV, own picture

Ill.24: Serial vision V, own picture

Ill.25: Serial vision VI, own picture



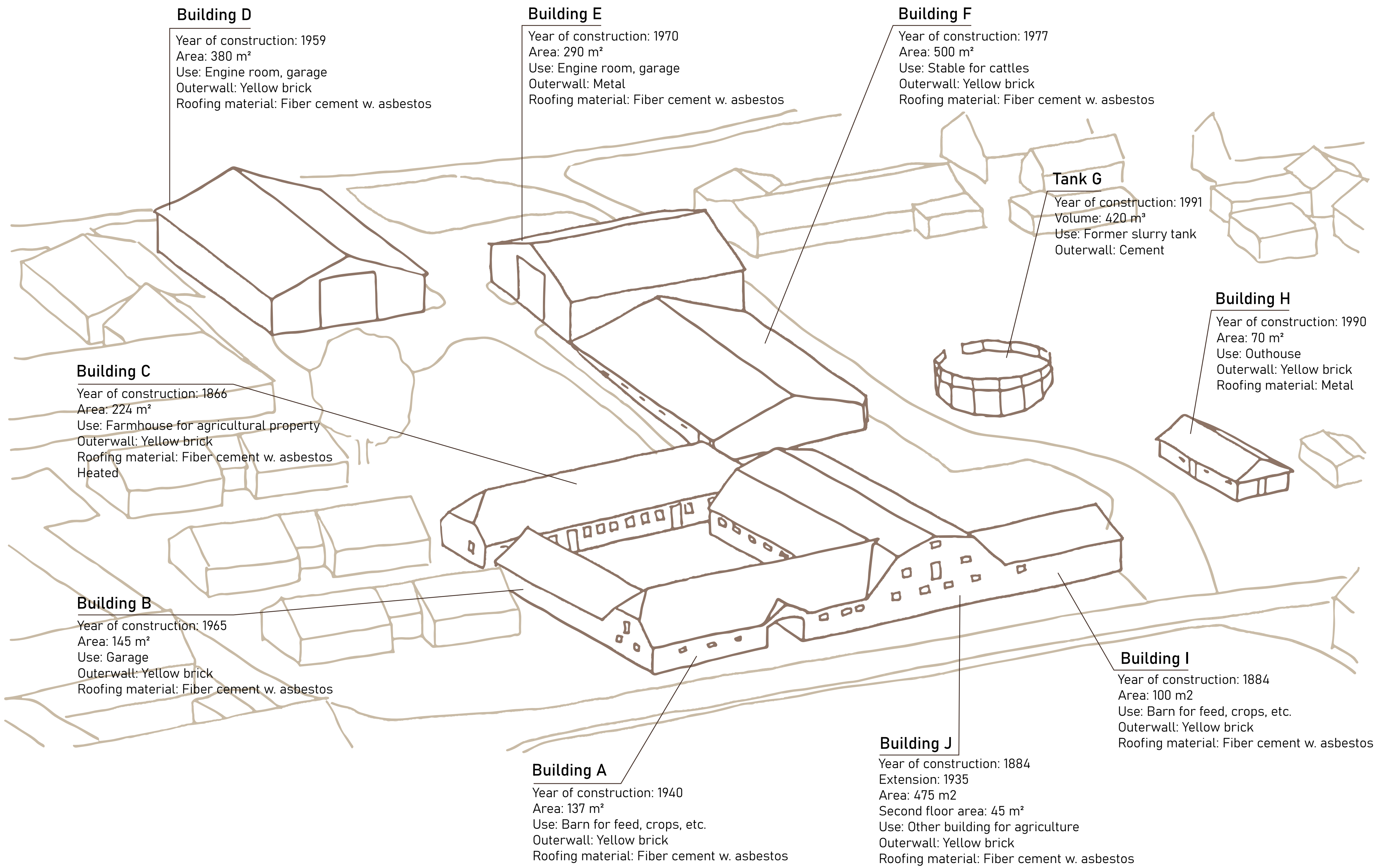
Ill.26: Serial vision rute

state of the art

When doing transformations the current state of the existing buildings must be explored to understand the physical conditions and properties.

Illustration 27 presents an overview of the entire site and the various buildings included. The site features a four-wing farm structure with an opening oriented to the north, overlooking the village pond. Behind this building, three additional barns are situated. Adjacent to the four-wing farm are a closed slurry tank and a henhouse. The site also includes a gravel road that runs from the northern to the southern end, as well as large, underutilised open green areas. The farm is located on a hill, with Buildings D and E positioned at the highest point (Appendix 05: City Profile).

To gain deeper insight into the current condition of the farm's buildings and properties, an overview was compiled using data from BBR, the Danish Building and Housing Register (Vurderingsstyrelsen, n.d.). This overview includes details such as the total floor area in square metres, construction materials, and the year of construction, providing a comprehensive understanding of the cattle farm's existing state. This information, combined with data gathered during the site visit, enabled the reconstruction of the cattle farm in 3D and CAD drawings, which supported the sketching phase of the design process.



Ill.27: Diagram state of the art

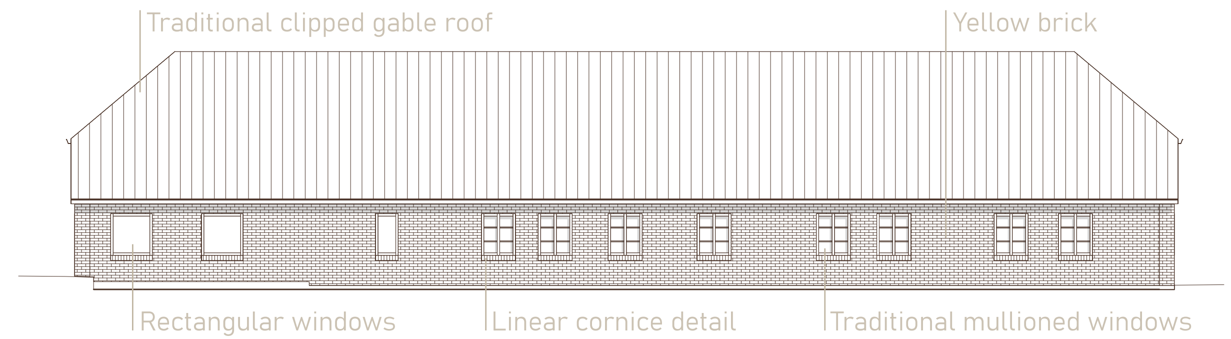
facade study

To gain a better understanding of the buildings and their exterior expressions, a façade study has been developed. Since the project includes a large number of buildings that are interconnected in various ways, the study has been simplified by dividing it into two parts. The first part focuses on investigating the components and details of the traditional four-wing building, while the second part examines the separately located utility buildings. For individual facades of all buildings, see Appendix 06: Original facades.

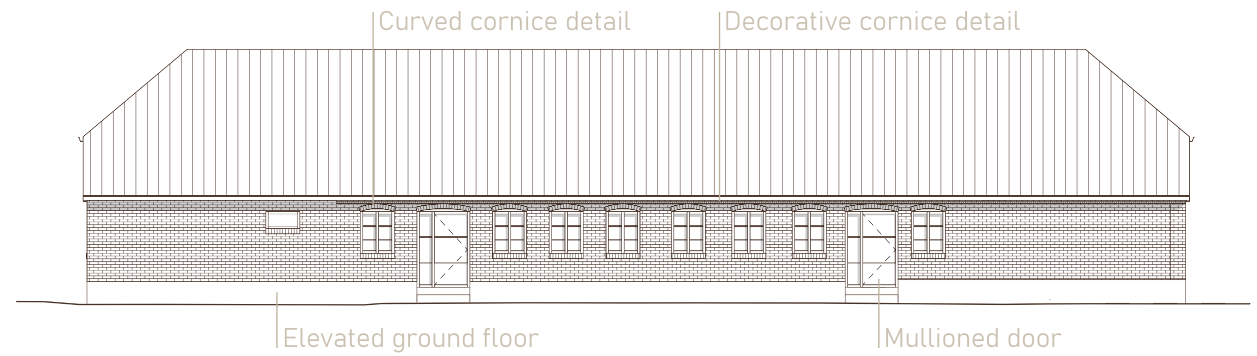
Four-wing buildings

The four-wing building primarily consists of cross-bond brick façades with various details. The façades differ in expression, featuring both curved and straight cornice details, as well as simpler, more streamlined facades without cornices. The buildings also vary in roof shape, including gable, clipped gable, and gambrel roofs. The windows differ in dimensions and shapes, with some being mullioned and curved, while others are simple and rectangular.

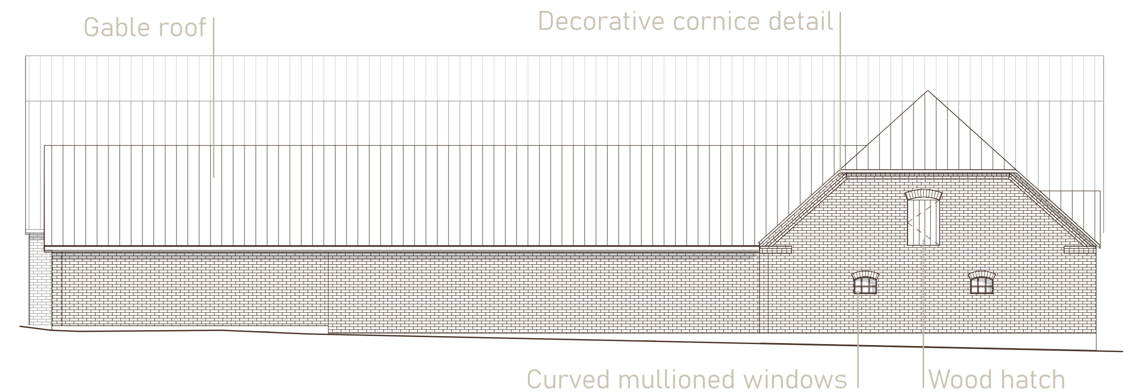
These various building parts and details contribute to telling the story of the farm's development over the years. The traditional features, such as the brick elements, have been preserved, and it is evident that the farm has undergone significant development, as outlined in the farming history section (see p. 19).



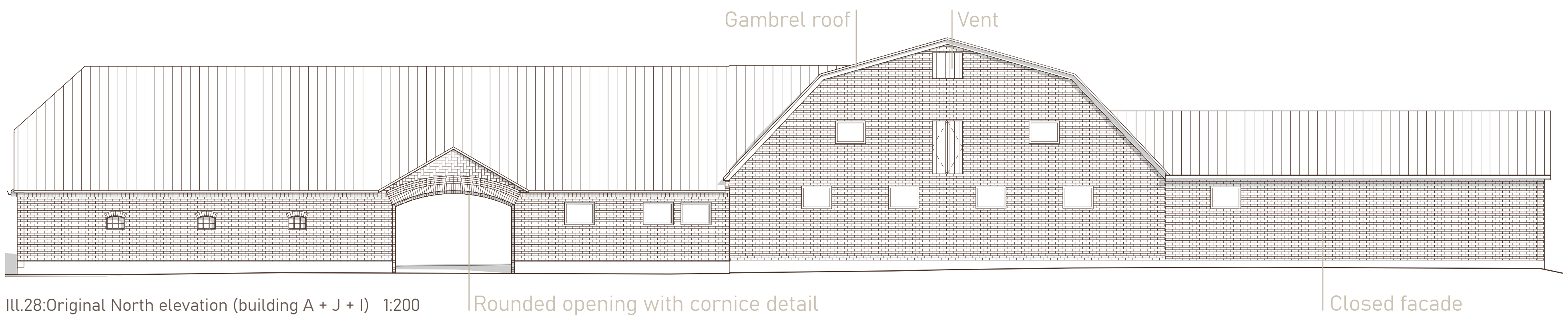
Ill.29:Original south elevation (building C) 1:200



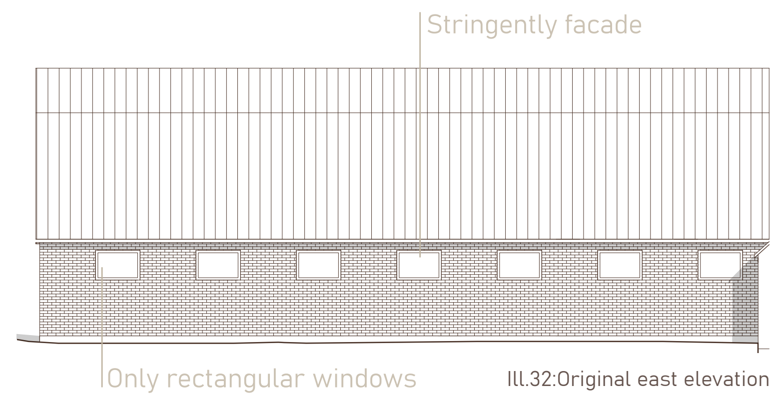
Ill.30:Original north elevation (building C) 1:200



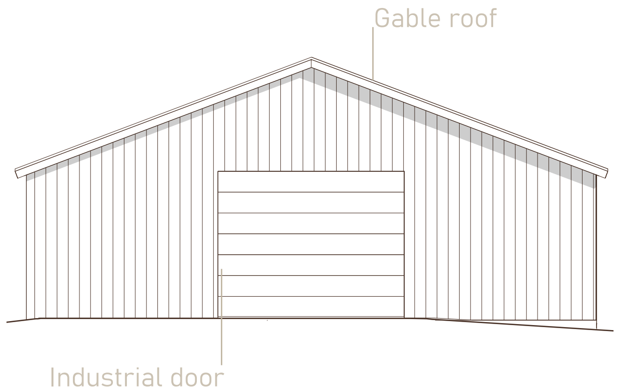
Ill.31:Original east elevation (building A + B) 1:200



Ill.28:Original North elevation (building A + J + I) 1:200



Ill.32:Original east elevation (building J) 1:200

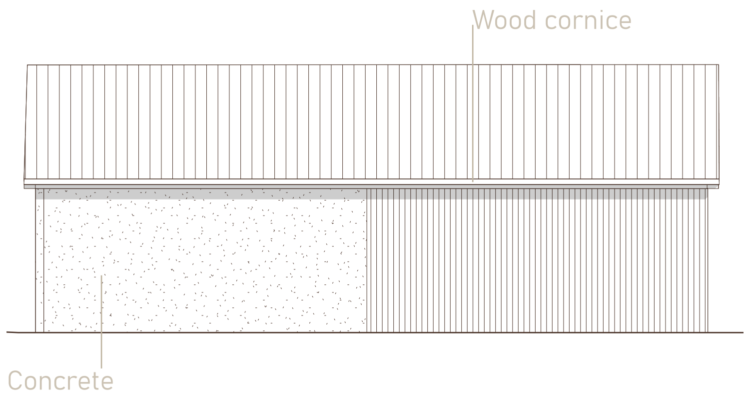


Ill.33:Original north elevation (building D) 1:200

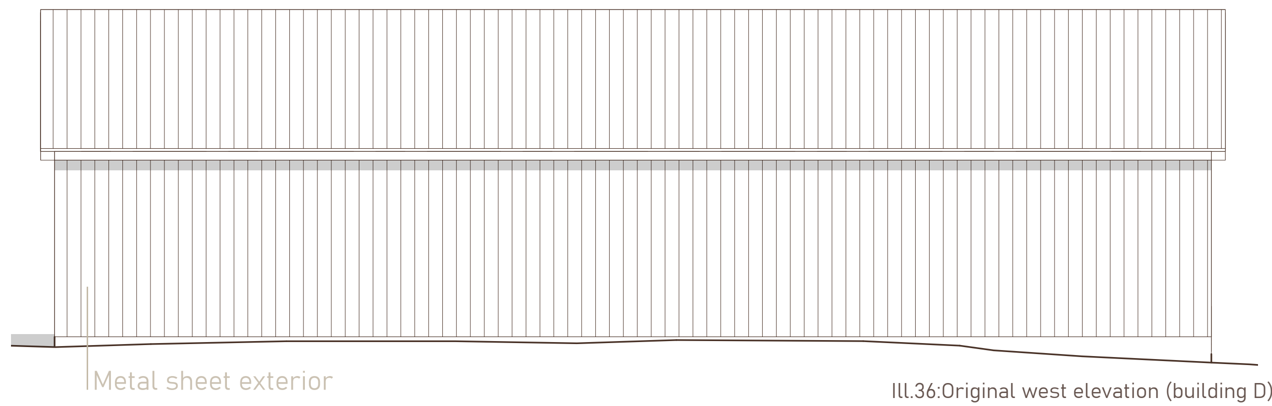
Utility buildings

The utility buildings' facades emphasise their industrial identity, with the large machinery barns featuring closed facades and a prominent industrial door. The buildings, constructed from metal sheeting and concrete, along with their simple gable roof design, further accentuate the industrial character.

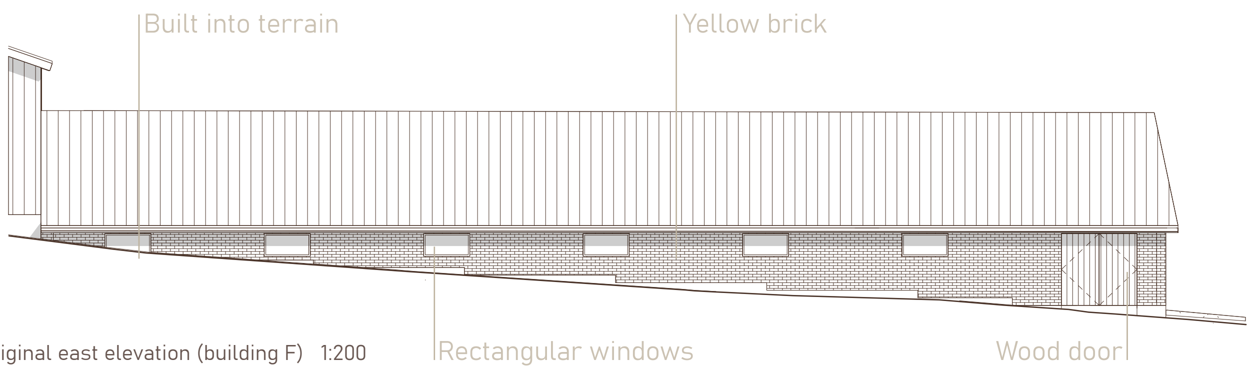
The cattle barn, located within the terrain (see illustration 35), features a combination of brick and metal sheet facades. There are no cornice details or mullioned windows; instead, the building presents a strict expression, characterised by simple rectangular windows.



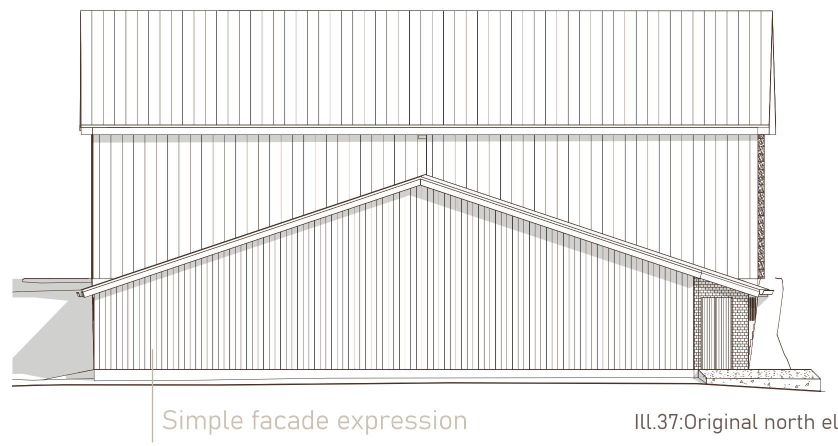
Ill.34:Original south elevation (building E) 1:200



Ill.36:Original west elevation (building D) 1:200



Ill.35:Original east elevation (building F) 1:200



Ill.37:Original north elevation (building E + F) 1:200

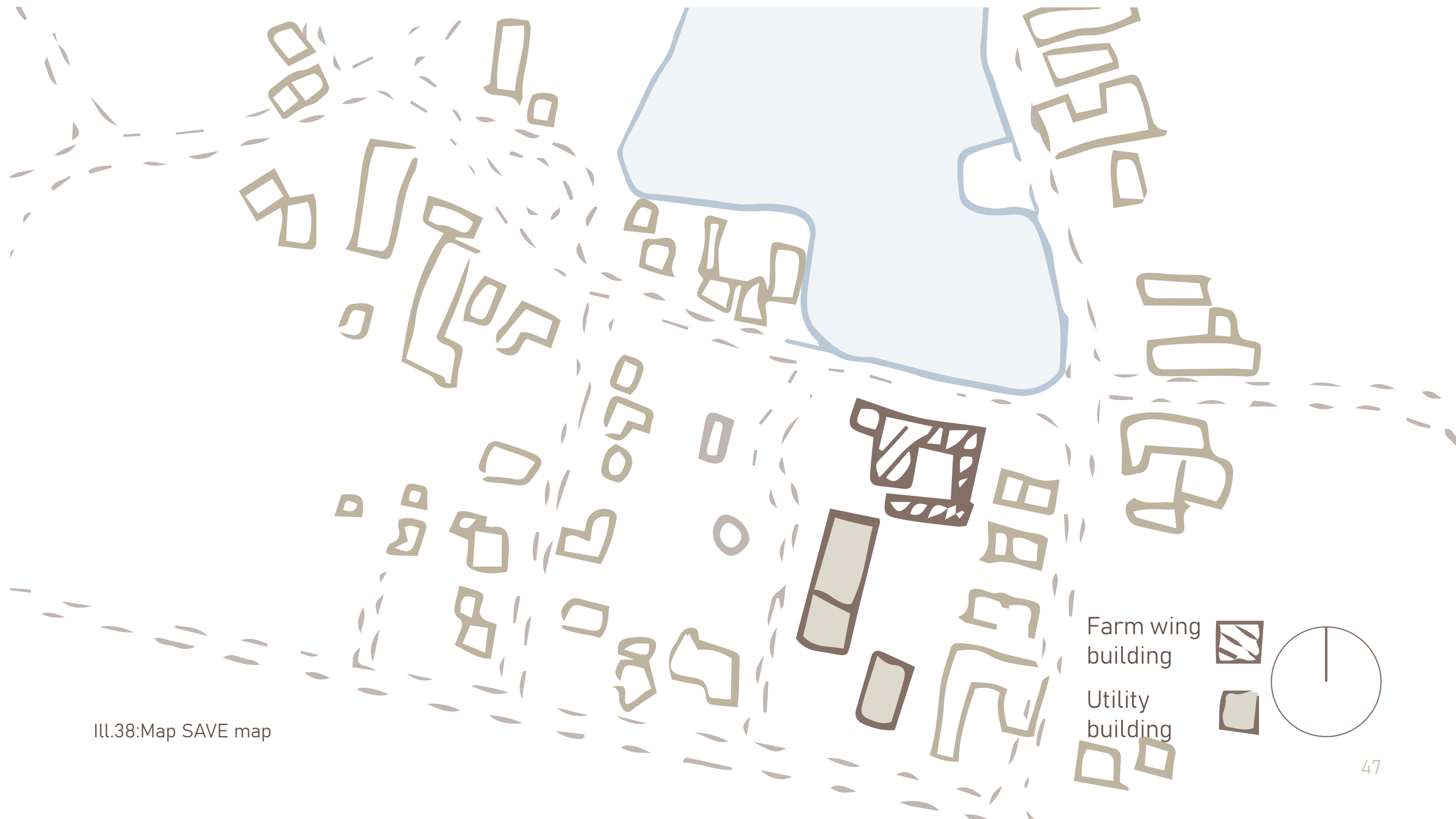
SAVE

To document and understand the preservation values of an existing building, the SAVE method can be employed. SAVE (Survey of Architectural Values in the Environment) identifies the architectural and historical significance of buildings and cities. Developed by the Danish Agency for Culture (Danish: Kulturstyrelsen), this method is intended for use by officials and municipalities in various contexts. It offers an overview and serves as a guiding tool for evaluating the conservation value of buildings. (Slots- og Kulturstyrelsen, 2021)

The SAVE method consists of two parts: the first involves mapping and examining city structures, while the second focuses on the registration of existing buildings. Earlier in this thesis, a series of site analyses were conducted, including a general structural analysis and an examination of the city's image, supported by a historical description. With these, the first part of the SAVE method has been addressed. Therefore, this section will focus on the second part—the registration of the buildings.

When registering the built environment, five parameters must be considered: architectural value, cultural-historical value, environmental value, originality, and current condition (Kulturarvsstyrelsen, 2011).

For clarification, the analysis has been divided into two sections. See appendix 07: SAVE, for the full SAVE analysis of each individual building. The sections focus, as with the facade study, on the four-wing farm and the utility buildings, as these two building types are architecturally related. Buildings H and I have been excluded from this overview because they were deemed not worth preserving and have been demolished as part of the cattle farm's design process.



Ill.38:Map SAVE map

Four-wing building

The composition of the building forms the layout of the four-wing structure, referencing traditional and historical farms (see Danish farm history, p. 19). This includes the living wing, an old horse barn now converted into a garage, an old grain storage building, and an old cattle barn, which has been repurposed as a large garage and gathering space.

Cultural-historical value

As previously mentioned, the layout of the four-wing farm is a reference to traditional farming, where all functions were housed within a square structure. Each building served a distinct purpose for the farm's operation, supporting both livestock breeding and cultivation. These historical references have been preserved by maintaining the four-wing footprint.

Architectural value

The building facades are primarily constructed of traditional yellow bricks, featuring various brick cornices and details. The window openings vary from building to building, ranging from traditional mullioned and curved windows to simpler rectangular ones, reflecting the buildings' evolution within the farming industry over time.

Environmental Value

The four-wing building is oriented directly towards the village pond. The entrance port, located on this façade, is easily recognisable in the city image (See serial vision p. 38), emphasising the building's identity in Råby. The living wing, positioned furthest from the road, is the first building encountered when passing through the entrance port. The four-wing structure forms an enclosed shape, with the buildings facing inward towards an inner courtyard.

Originality

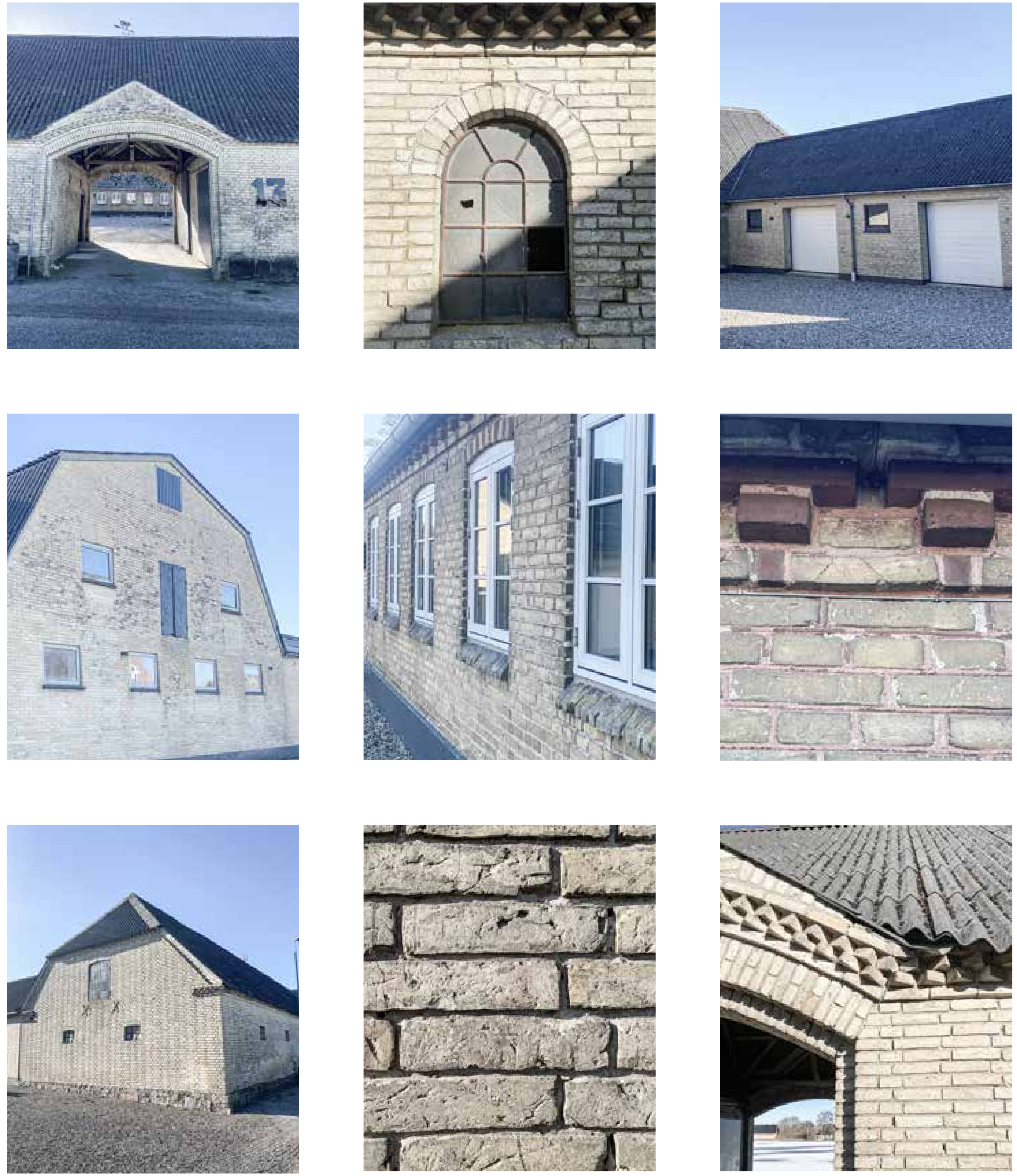
The various buildings differ in terms of originality. While all buildings have been preserved on their original footprint, maintaining the four-wing structure, the living wing and garage have undergone renovations to optimise their respective functions.

Conditions

The condition of the different buildings varies depending on their year of construction and whether they have undergone renovations. As shown in the images in illustration 39, some parts of the buildings are worn and contain traces of patina, while others appear to be renovated and in good condition.

Evaluation

In general, the four-wing farm consists of various buildings that bear traces of the cultural heritage of agricultural farming, with the development of the farming industry's history evident in the details of their façades and overall building structure. Therefore, this part of the site has been deemed worthy of preservation during its transformation into new functions.



Ill.39: SAVE four wing pictures

Utility buildings

The utility buildings consist of several separate, voluminous barns. Two of these are machinery barns used for storing large machines and tools for farming, while the stock barn currently serves as the cattle barn, providing shelter for the cattle. Finally, an old slurry tank has been closed off and repurposed as a patio, offering a space for relaxation and a view of the village pond.

Cultural-historical Value

The utility buildings articulate an industrial character, where functionality is prioritised. The machinery barns, positioned towards the fields, facilitate easy access for large farming equipment. The separation of the cattle barn from the living wing reflects the later advancements in hygiene practices (see Danish farm history p. 19).

Architectural Value

In general, these buildings demonstrate an industrial character, characterised by their simple layout and form, with steel construction, metal sheets, and concrete as the primary façade materials. The machinery barn features a single large industrial door as its sole opening. The cattle barn, constructed of yellow bricks, highlights its connection to and proximity to the four-wing building. g.

Environmental Value

As previously described, the buildings are separate from the original four-wing structure. The two machinery barns are situated atop the hill, facing the fields to the south, giving them a prominent position within the city's image. Buildings E and F are connected, with the cattle barn integrated into the slope of the terrain. A gap between these two buildings connects them internally, allowing the farmer easy access to provide the cattle with hay stored in the machinery barn. Half of the slurry tank is embedded into the terrain, offering direct access from the hilltop and providing a view towards the village pond.

Originality

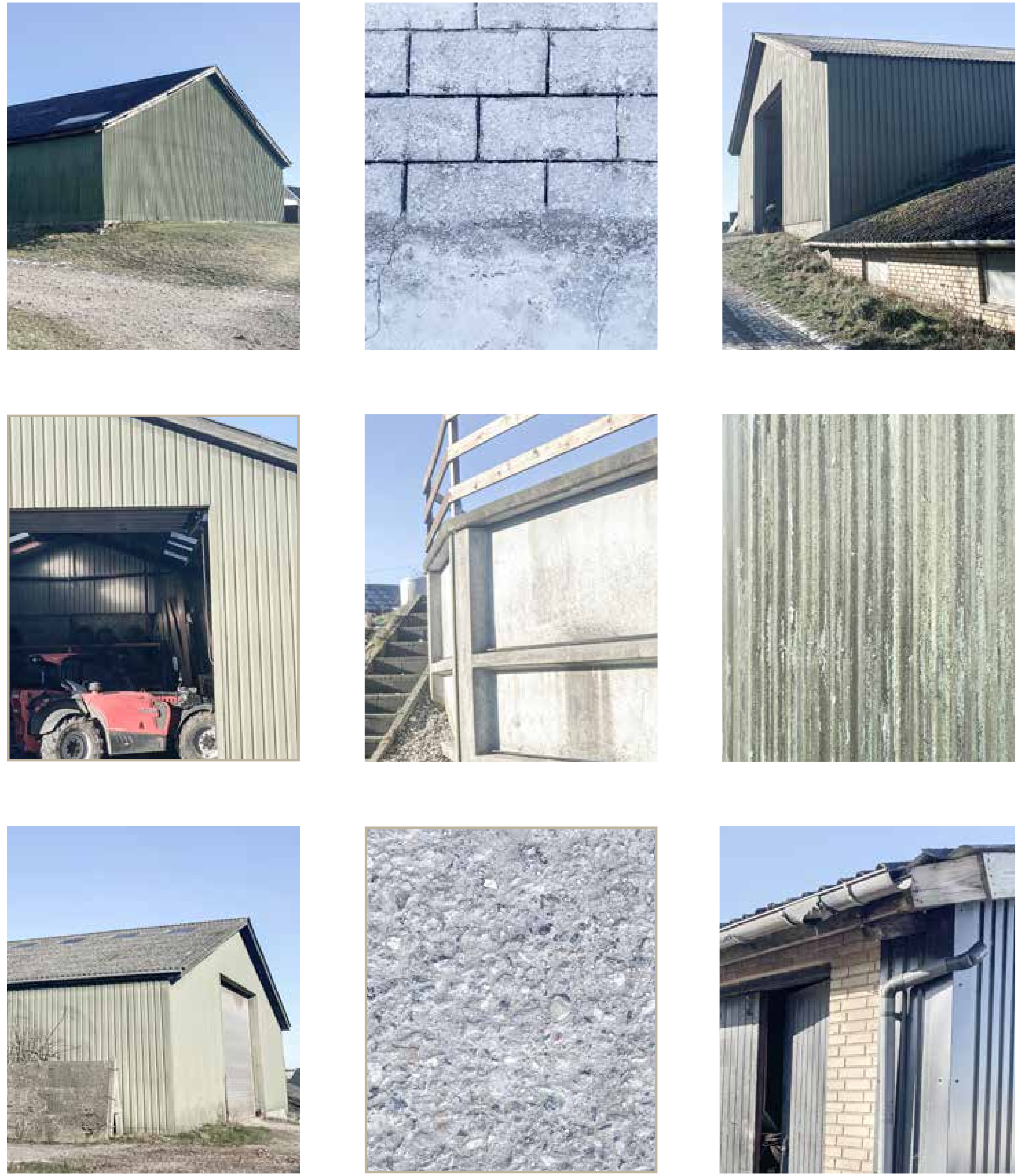
All the buildings retain their original state, showing signs of patina from years of use. Some have undergone minor material replacements on their facades.

Conditions

In general, the buildings are in good condition. The steel frames are intact, and the facade materials remain in good shape.

Evaluation

Since the utility buildings highlight the history of the farming industry, they provide cultural significance by showcasing this heritage. To preserve this value, these buildings are considered worthy of partial preservation and should be transformed with respect, ensuring that their industrial and functional shapes are maintained.



Ill.40:SAVE utility buildings pitcures

Ill.41: Drawing garden

users

Demographic | Potential users

The objective of the next section is to gain a deeper understanding of the village's demographic profile and to determine the potential users for this thesis. This section is based on desktop research, utilising information and statistics from the municipality and official parish records. Additionally, three interviews were conducted, providing valuable insights that informed the process and development of the project (Appendix 08: Interview).

demographic

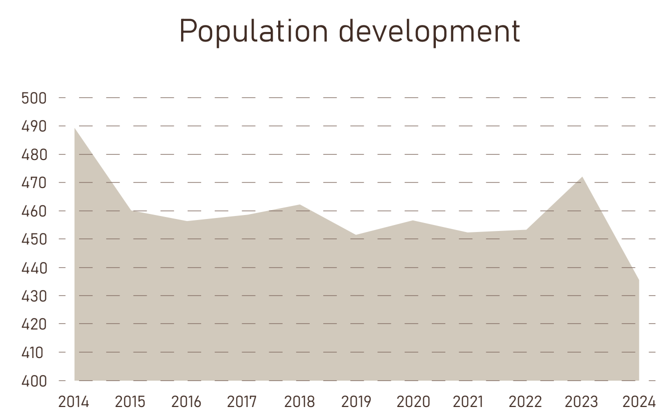
To gain a greater understanding of the potential users for the design proposal, an investigation into the general demographics of rural districts in Randers Municipality, with a specific focus on Råby parish, has been conducted. This examination provides insights into the number and types of residents, which, together with the previous analyses of Råby, will serve as a guiding tool for identifying potential users.

According to a report on rural district development by Randers Municipality, the motivation for moving to small rural districts is emphasised, with affordable housing, recreational areas, and strong local communities being key factors (Randers Kommune, 2021, B). In the report, Råby is placed within sub-region 3, which is characterised by a declining or stagnant population growth. Approximately 25-28% of the population is aged 65 and over, indicating that the majority of residents are elderly (Randers Kommune, 2021,B).

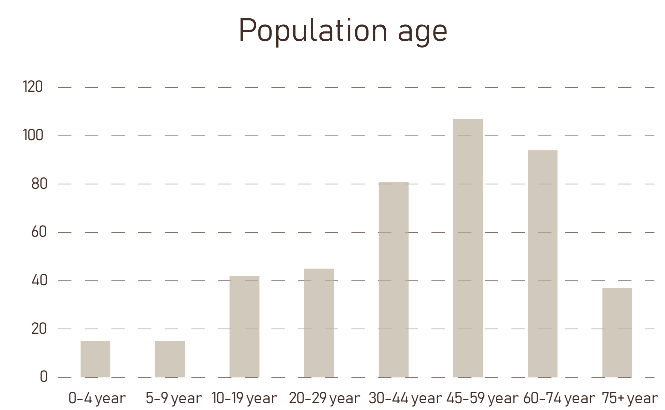
A parish report by the National Church Education and Research Centre (Danish: Folkekirkens Uddannelses- og Videnscenter) provides a more precise insight into the population of Råby parish. According to the report, 436 residents currently live in the parish, and as shown in diagram 42, a small decrease in population has occurred since 2014 (Kirkestatistik, 2024). Regarding the types of residents, the diagram 43 illustrates a dominant number of adults and elderly residents, which aligns with the report on rural district development by Randers Municipality (Kirkestatistik, 2024, p. 3).

The combination of a predominantly elderly population, along with the increasing need for adaptable housing solutions, highlights the importance of diversifying the available dwelling typologies.

Through an interview with the Head of Development at a major public housing association (Appendix 08: Interview), the focus on public housing became particularly relevant (Appendix 09: Public housing). He emphasised the importance of ensuring housing opportunities that accommodate the changing living situations of residents, such as losing an elderly partner or going through a divorce. To address this, the inclusion of public housing in the transformation of the cattle farm would contribute to a more diverse range of dwelling options in Råby, thus ensuring the city's development through the concept of housing rotation.



Ill.42: Population development, Kirkestatistik (2024)



Ill.43: Population age, Kirkestatistik (2024)

potential users

Through the examination of Råby's current population, the project aims to integrate public housing opportunities that prioritise community, addressing the needs of the potential users illustrated on page 57.

As discussed in the previous section, Råby has a predominantly elderly and adult population, who primarily occupy the single-family houses and farms within the village.

Implementing public housing in Råby will not only promote housing rotation but also enable adults and elderly residents to move into more suitable homes, allowing them to remain in their preferred local community. Additionally, this will support single residents whose marital status has changed and who are now living alone with children, helping them stay in the community they are familiar with.

Lastly, established families seeking to move away from the larger city and closer to nature, while becoming part of a local community, would benefit from the introduction of public housing. This would provide an opportunity for families to settle in Råby and become an integral part of the smaller, close-knit community within the broader local area of Råby.

These user profiles will be utilised throughout the design process and serve as the foundation for the upcoming technical investigation into implementing housing rotation in a village like Råby. For this section, generic plans have been created for each representative user (Appendix 10: Fictive plans).

Ill.44: Sketch users

The Family consists of the couple that has two younger children, they are currently living in an apartment in Aarhus, but dreams of more space for the family to grow.

Needs

Seeks local community

Live closer to nature and open land

Space for expansion

The Single mother lives alone with her children after a divorce, living nearby her family is essential to keep the everyday life running.

Needs

Seeks local community or stay in the current

Affordable housing

Sharing children with later partner

The Pair, adult or elderly partners have lived in Råby for many years. They have three adult children that has moved away due to studies, they often visit in the weekend.

Needs

Less space now without children

Seeks local community or stay in the current

The Elderly an elderly- has had a single-family house or local farm in Råby parish, where they lived with their later partner most of their life lives.

Needs

Seeks local community or stay in the current

No loneliness

Physical limits

Ill.45:Drawing houseing unit

housing rotation

Approach | Conventional moving principle | Housing rotation principle

Conclusion & learnings

Based on the concept of housing rotation (p. 24), this section aims to further explore this principle and examine the potential reduction in climate footprint that it can offer when compared to conventional moving practices.

approach

This section seeks to examine and compare the climate footprint of two moving principles within Råby: the conventional moving principle and the concept of housing rotation. Based on the users defined in the previous section, a series of generic typologies, along with generic plan drawings inspired by actual representative addresses in Råby and Randers, are presented. These addresses serve as baselines for generic typologies representing the typical dwelling types of different users within and around Danish villages over their lifecycle. These typologies will be used to inform and support the examination (Appendix 10: Fictive plans).

Two sets of scenarios for each generic typology will illustrate the reduced climate footprint achieved through renovations. The first scenario examines the operational energy's climate footprint of the existing, non-renovated generic typologies. The second scenario investigates both the operational and embodied energy's climate footprints from the renovations of the same typologies.

The two moving scenarios will be compared alongside the principle of new construction. The initial hypothesis posits that implementing housing rotation in cities like Råby will reduce the overall climate footprint.

Method

The analysis focuses on comparing the climate footprint of the various typologies before and after a renovation of the building envelope. This renovation includes re-insulating the roof and exterior walls, installing a new floor construction, and replacing the windows to optimise operational energy demand.

The building elements and construction parts are fictitious but are based on the original year of construction, along with inspiration from the case studies in the report "Klimaeffektiv Renovering" (Kanafani, K., Lund, A. M., Schjødt Worm, A., Due Jensen, J., Birgisdottir, H., & Rose, J., 2021). The energy consumption prior to the renovation is based on the BUILD report "Varmebesparelse i eksisterende bygninger: Segmentering" (Kragh, J. & Aggerholm, S., 2020), where the typology and the year of construction are the key determining factors. An emission factor for the specific energy source is then applied to establish the climate footprint (HBEMO (n.d.) & Kanafani, K., Lund, A. M., Schjødt Worm, A., Due Jensen, J., Birgisdottir, H., & Rose, J., 2021).

The energy renovation of the typologies is based on the national energy requirements for renovations, as outlined in the schedule below (Bygningsreglementet, n.d.). The global warming potential of the materials used in the renovation is examined through a Life cycle assessment (LCA) over a 50-year period. Using the software tool LCAbyg, along with generic data from the program and additional data from Environmental Product Declarations (EPDs) for specific materials, the assessment is carried out (Appendix 11: LCA fictive plans).

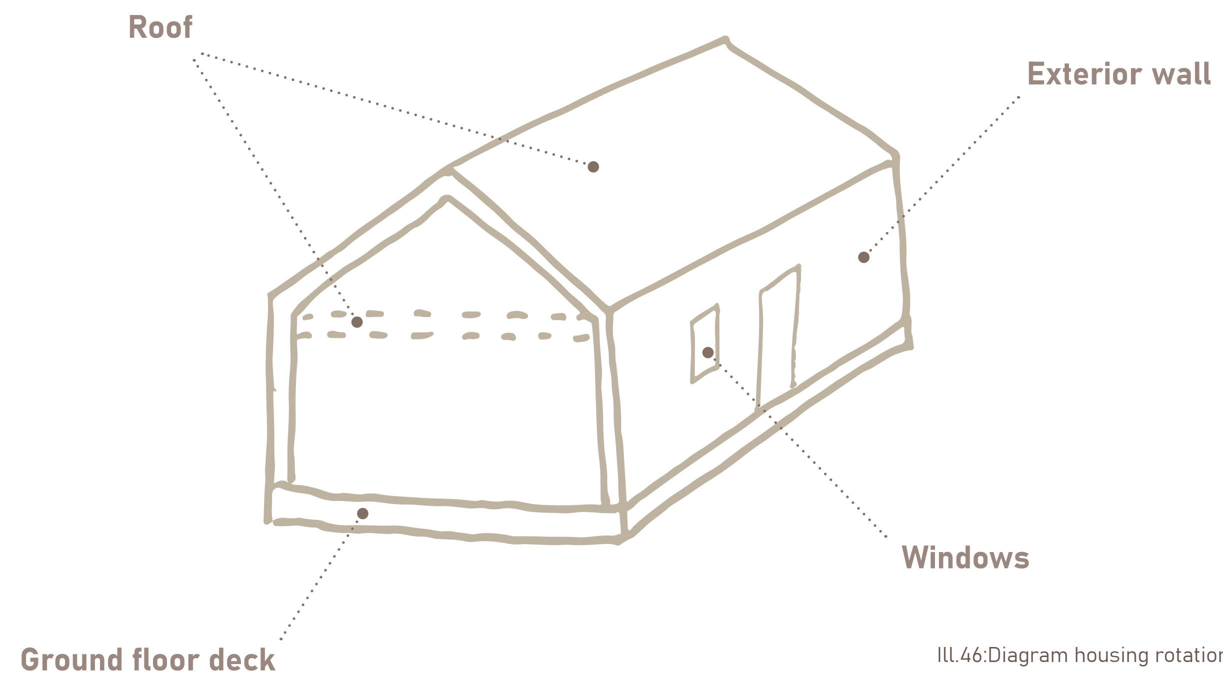
Minimum required U-values

Building part	[W/m²K]
Roof	0,12
Exterior walls	0,18
Ground floor deck	0,10

The energy consumption of the renovated typologies is calculated through a heat loss calculation, incorporating the fictive building's geometry and the updated U-value after renovation. An emission factor is also applied to convert the results into the climate footprint.

From the climate footprint after renovation, a yearly average is calculated to facilitate a clearer comparison between the before and after scenarios.

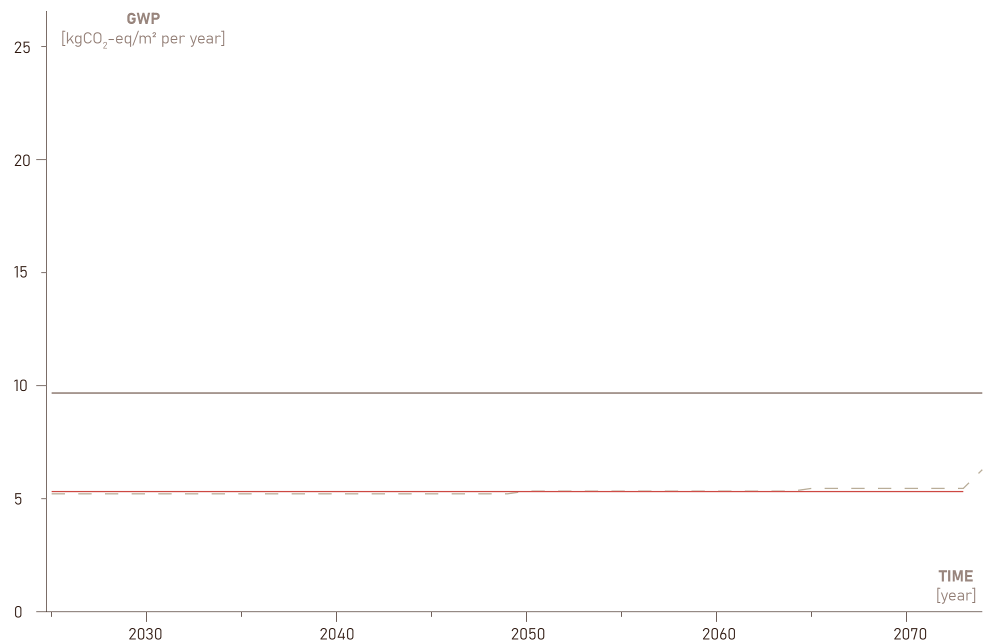
The following pages will present the different generic typologies, along with the building elements before and after renovation. Additionally, a diagram will be provided to compare the climate footprint before and after renovation.



Ill.46:Diagram housing rotation approach

apartment

The apartment is a small unit in a larger residential building based on an actual building in Randers, which was renovated in 1987 (Appendix 10: fictive plans). As shown in Illustration 47, the building parts before and after renovation are visualised. In Illustration 46, a graph is presented, illustrating the climate footprint before and after renovation. The graph demonstrates that the renovation has reduced the climate footprint by nearly a third. This shows that a renovation optimising operational energy can significantly reduce the climate footprint, even when additional materials are added to the building's envelope. These results will be further analysed in the comparison of the two moving principles—conventional and housing rotation—on page 70-73.



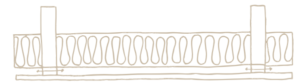
Average operational energy before renovation: **9,68** [kgCO$_2$-eq/m² per year]

Embodied & operational energy after renovation [kgCO$_2$-eq/m² per year]

Average embodied & operational energy after renovation: **5,3** [kgCO$_2$-eq/m² per year]

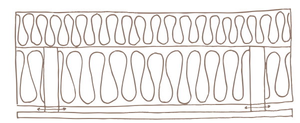
Ill.47: Apartment results

Roof before renovation



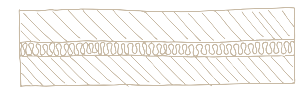
Properties
U-value: 0,446 [W/(m²K)]
Thickness: 207 [mm]

Roof after renovation



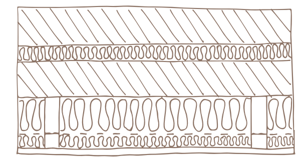
Properties
U-value: 0,118 [W/(m²K)]
Thickness: 392,5 [mm]
Material GWP: 0,348 [kgCO$_2$-eq/m² per year]

Exterior wall before renovation

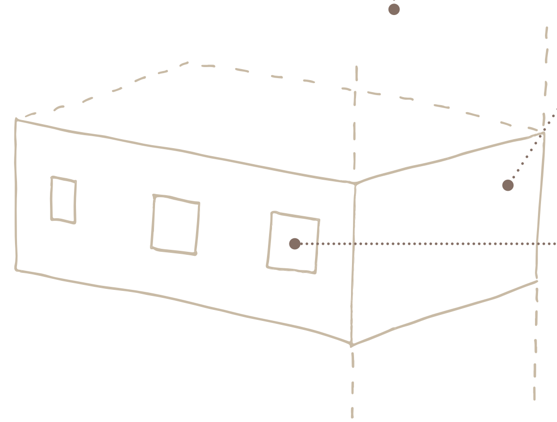


Properties
U-value: 0,665 [W/(m²K)]
Thickness: 271 [mm]

Exterior wall after renovation



Properties
U-value: 0,175 [W/(m²K)]
Thickness: 438,5 [mm]
Material GWP: 0,217[kgCO$_2$-eq/m² per year]



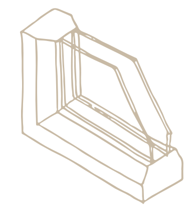
Ill.48: Apartment before & after renovation

Appartment: 67 [m²]
Built: 1935 [year]
Renovated: 1987 [year]
Facade: Red brick
Roof: Red tile

Before renovation
Heating source: District heating
Energy requirement:
1979-: 110,25 [kWh/m² per year]

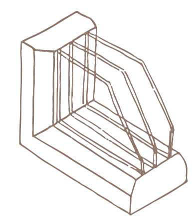
After renovation
Heating source: District heating
Energy requirement:
Heating: 44,04 [kWh/m² per year]
Electricity: 1,9 [kWh/m² per year]

Windows before renovation



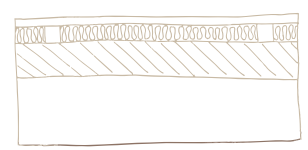
Properties
U-value: [2,8 W/(m²K)]
g-value: 0,53
a 2-layer thermo window with alu/wood frame

Windows after renovation



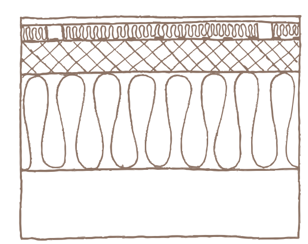
Properties
U-value: 1,15 [W/(m²K)]
g-value: 0,45
a 3-layer window with alu/wood frame
Material GWP: 0,388 [kgCO$_2$-eq/m² per year]

Floor deck before renovation



Properties
U-value: 0,662 [W/(m²K)]
Thickness: 370 [mm]

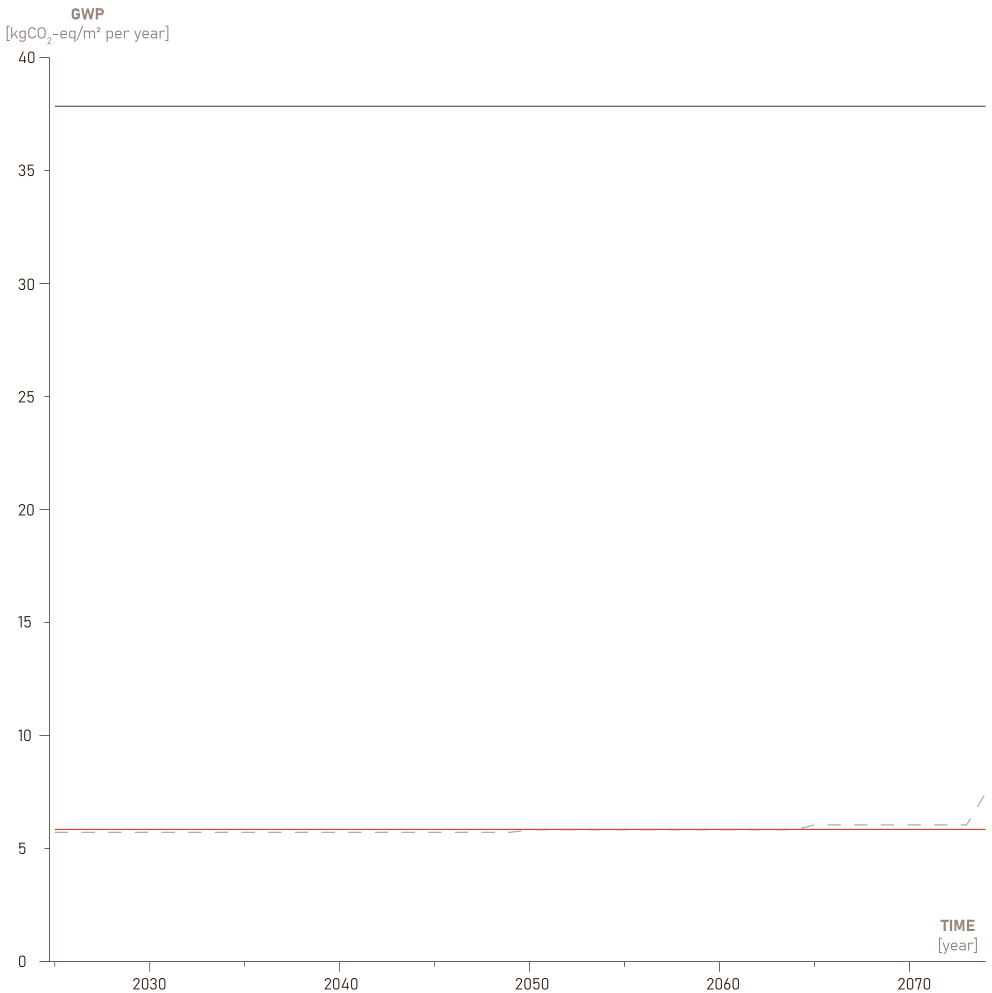
Floor deck after renovation



Properties
U-value: 0,09 [W/(m²K)]
Thickness: 670,5 [mm]
Material GWP: 1,215 [kgCO$_2$-eq/m² per year]

townhouse

The townhouse is a smaller housing unit located in Råby, built in 1989 (Appendix 10: Fictive plans). Illustration 50 shows the before and after renovation of its various building parts. The graph (Ill. 49) illustrates that the climate footprint of the renovation for this typology has been reduced by half, compared to the footprint before the renovation. These results will also be incorporated into the later analysis of the moving principles.



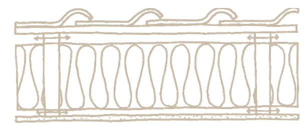
Average operational energy before renovation: **13,37** [kgCO$_2$-eq/m² per year]

Embodied & operational energy after renovation [kgCO$_2$-eq/m² per year]

Average embodied & operational energy after renovation:
5,52 [kgCO$_2$-eq/m² per year]

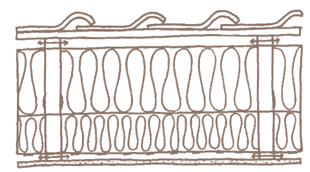
Ill.49: Townhouse results

Roof before renovation



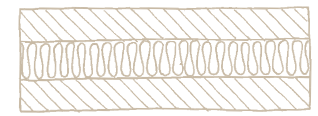
Properties
U-value: 0,283 [W/(m²K)]
Thickness: 365 [mm]

Roof after renovation



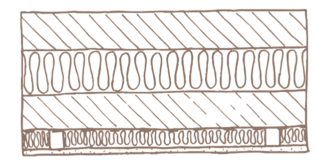
Properties
U-value: 0,117 [W/(m²K)]
Thickness: 485 [mm]
Material GWP: 0,427 [kgCO$_2$-eq/m² per year]

Exterior wall before renovation

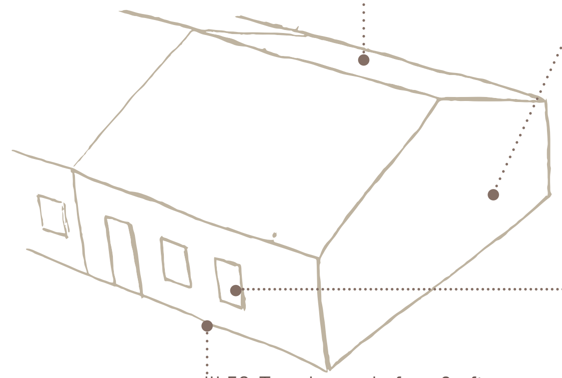


Properties
U-value: 0,305 [W/(m²K)]
Thickness: 351 [mm]

Exterior wall after renovation



Properties
U-value: 0,18 [W/(m²K)]
Thickness: 418,5 [mm]
Material GWP: 0,450 [kgCO$_2$-eq/m² per year]



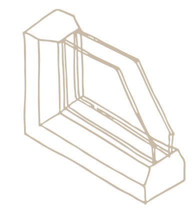
Ill.50: Townhouse before & after renovation

House: 75 [m²]
Built: 1989 [year]
Facade: Red brick
Roof: Red tile

Before renovation:
Heating source: Electric heating
Energy requirement:
1979-: 99,058 [kWh/m² per year]

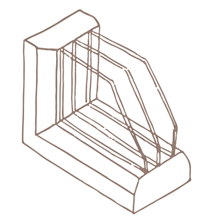
After renovation
Heating source: District heating
Energy requirement:
Heating: 46,43 [kWh/m² per year]
Electricity: 1,9 [kWh/m² per year]

Windows before renovation



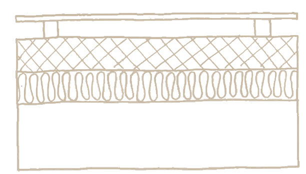
Properties
U-value: [2,8 W/(m²K)]
g-value: 0,53
a 2-layer thermo window with alu/wood frame

Windows after renovation



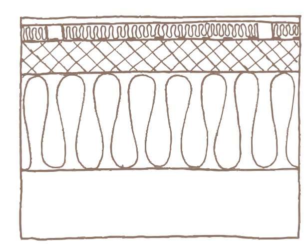
Properties
U-value: 1,15 [W/(m²K)]
g-value: 0,45
a 3-layer window with alu/wood frame
Material GWP: 0,286 [kgCO$_2$-eq/m² per year]

Floor deck before renovation



Properties
U-value: 0,388 [W/(m²K)]
Thickness: 470 [mm]

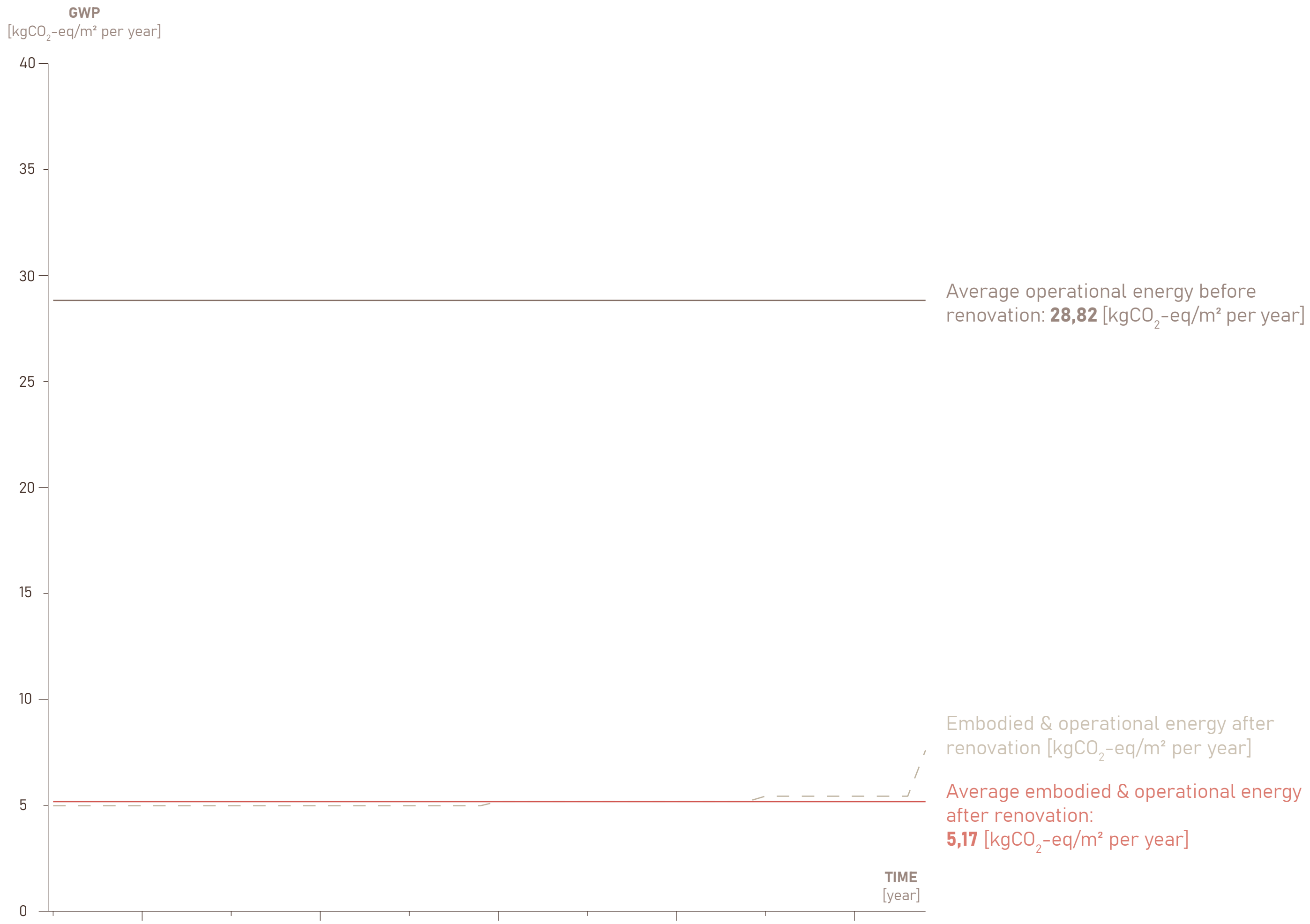
Floor deck after renovation



Properties
U-value: 0,09 [W/(m²K)]
Thickness: 670,5 [mm]
Material GWP: 1,828 [kgCO$_2$-eq/m² per year]

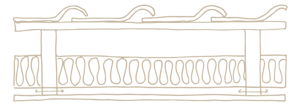
single-family house

The single-family house is a medium-sized dwelling, based on an address in Råby, which was renovated in 1981 (Appendix 10: Fictive plans). The building components of this house, before and after renovation, are presented in Illustration 52. The climate footprint was quite high prior to renovation (ill. 51), but after the renovation, it has been reduced by approximately 70%, resulting in a significant improvement in the building's climate footprint.



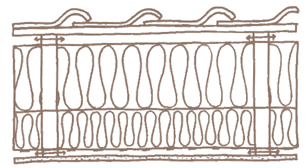
Ill.51: Single family-house

Roof before renovation



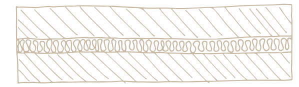
Properties
U-value: 0,446 [W/(m²K)]
Thickness: 310 [mm]

Roof after renovation



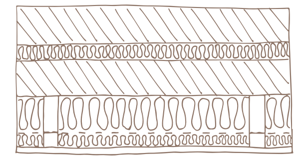
Properties
U-value: 0,117 [W/(m²K)]
Thickness: 480,5 [mm]
Material GWP: 0,492 [kgCO$_2$-eq/m² per year]

Exterior wall before renovation

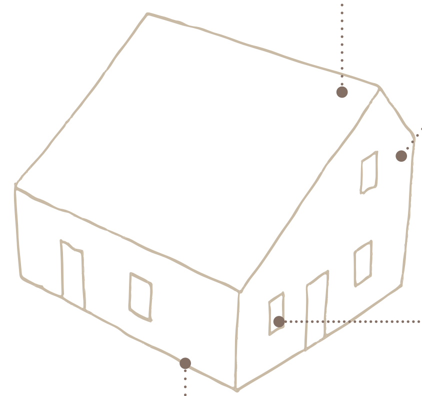


Properties
U-value: 0,665 [W/(m²K)]
Thickness: 271 [mm]

Exterior wall after renovation



Properties
U-value: 0,175 [W/(m²K)]
Thickness: 438,5 [mm]
Material GWP: 0,646 [kgCO$_2$-eq/m² per year]



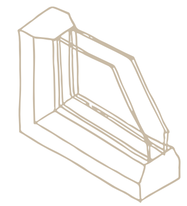
Ill.52: Single-family house before & after renovation

House: 120 [m²]
Built: 1936 [year]
Renovated: 1981 [year]
Facade: Red brick
Roof: Fiber cement

Before renovation
Heating source: Fluid fuel
Energy requirement:
1979-: 102,58 [kWh/m² per year]

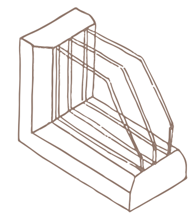
After renovation
Heating source: District heating
Energy requirement:
Heating: 42,18 [kWh/m² per year]
Electricity: 1,9 [kWh/m² per year]

Windows before renovation



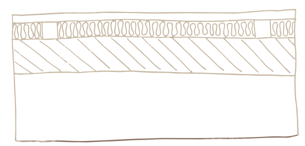
Properties
U-value: [2,8 W/(m²K)]
g-value: 0,53
a 2-layer thermo window with alu/wood frame

Windows after renovation



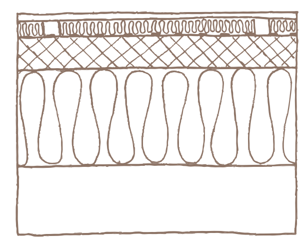
Properties
U-value: 1,15 [W/(m²K)]
g-value: 0,45
a 3-layer window with alu/wood frame
Material GWP: 0,677 [kgCO$_2$-eq/m² per year]

Floor deck before renovation



Properties
U-value: 0,662 [W/(m²K)]
Thickness: 370 [mm]

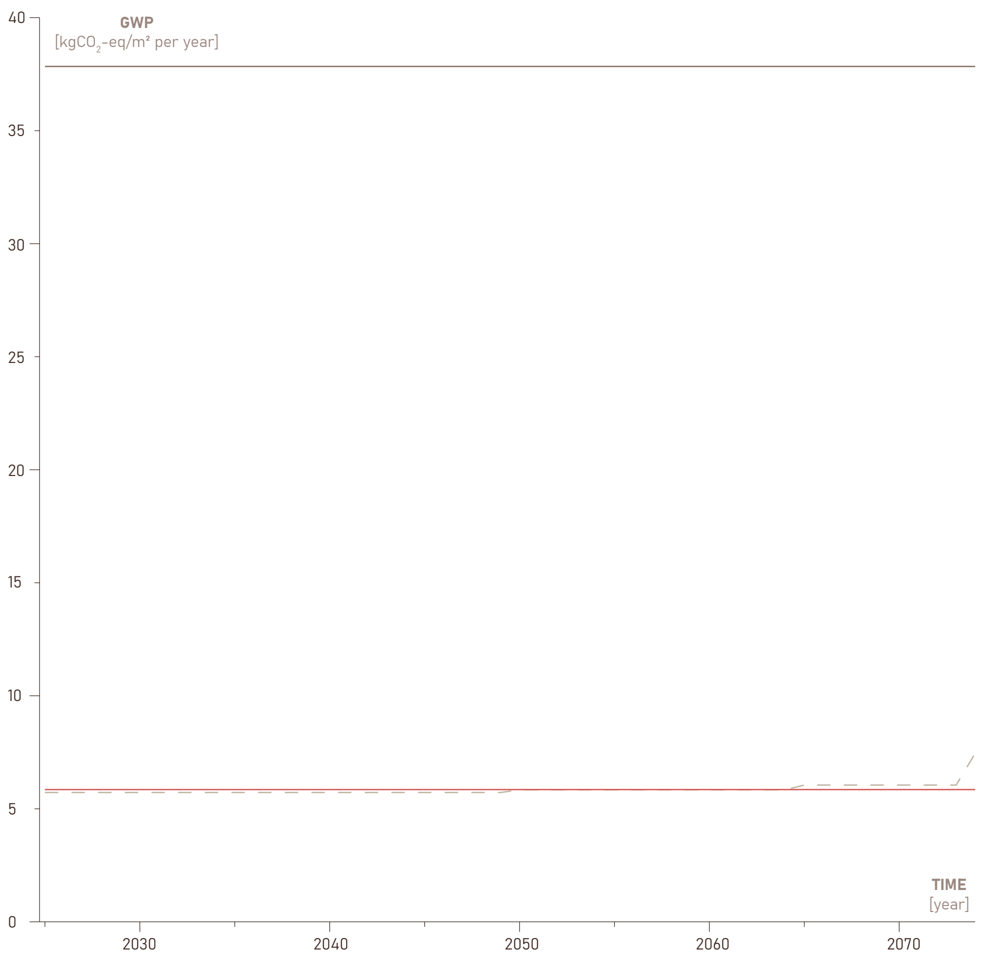
Floor deck after renovation



Properties
U-value: 0,09 [W/(m²K)]
Thickness: 670,5 [mm]
Material GWP: 1,828 [kgCO$_2$-eq/m² per year]

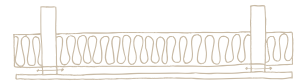
farm-wing house

The farm-wing house is the living wing of a farm located in Råby, renovated in 1979 (Appendix 10: Fictive plans). Illustration 54 provides an overview of the different building components for this generic typology, both before and after renovation. The graph in Illustration 53 shows that the climate footprint for this typology was quite high before the renovation. Following the renovation, there was a reduction of approximately 75%, significantly improving the climate footprint.



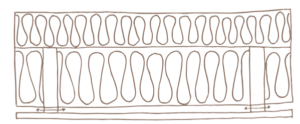
Ill.53: Farm-wing house

Roof before renovation



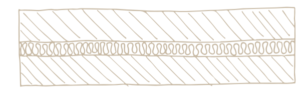
Properties
U-value: 0,446 [W/(m²K)]
Thickness: 207 [mm]

Roof after renovation



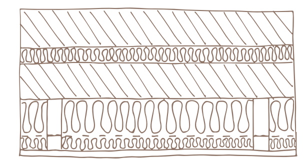
Properties
U-value: 0,118 [W/(m²K)]
Thickness: 492,5 [mm]
Material GWP: 0,358 [kgCO_2-eq/m² per year]

Exterior wall before renovation

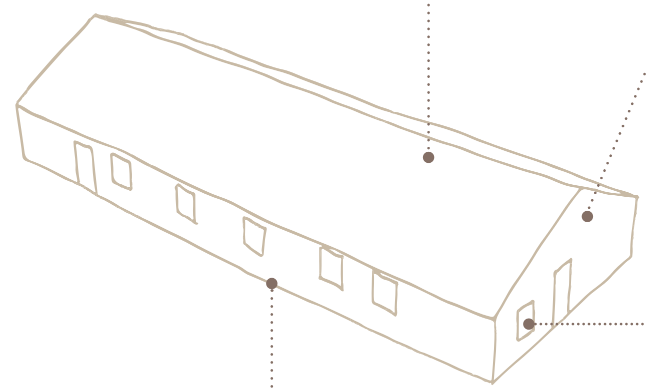


Properties
U-value: 0,665 [W/(m²K)]
Thickness: 271 [mm]

Exterior wall after renovation



Properties
U-value: 0,175 [W/(m²K)]
Thickness: 438,5 [mm]
Material GWP: 0,224 [kgCO_2-eq/m² per year]



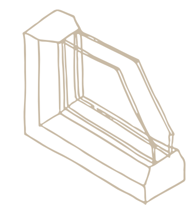
Ill.54:Farm wing house before & after renovation

House: 180 [m²]
Built: 1922 [year]
Renovated: 1979- [year]
Facade: Red brick
Roof: Fiber cement

Before renovation
Heating source: Fluid fuel
Energy requirement:
1979-: 134,67 [kWh/m² per year]

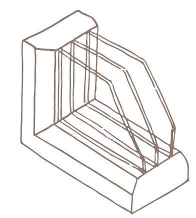
After renovation
Heating source: District heating
Energy requirement:
Heating: 54,04 [kWh/m² per year]
Electricity: 1,9 [kWh/m² per year]

Windows before renovation



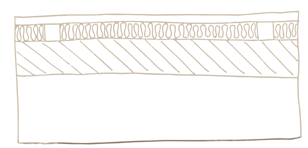
Properties
U-value: [2,8 W/(m²K)]
g-value: 0,53
a 2-layer thermo window with alu/wood frame

Windows after renovation



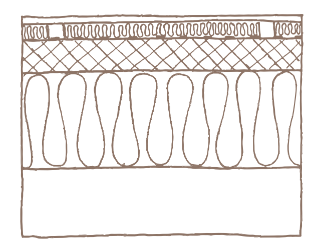
Properties
U-value: 1,15 [W/(m²K)]
g-value: 0,45
a 3-layer window with alu/wood frame
Material GWP: 0,390 [kgCO_2-eq/m² per year]

Floor deck before renovation



Properties
U-value: 0,662 [W/(m²K)]
Thickness: 370 [mm]

Floor deck after renovation



Properties
U-value: 0,09 [W/(m²K)]
Thickness: 670,5 [mm]
Material GWP: 1,828 [kgCO_2-eq/m² per year]

conventional moving principle

Illustration 55 demonstrates a generalised moving scenario of a family of four, following one main individual throughout their lifetime. This scenario is based on a typical, fictive moving pattern, which in this investigation is defined as the conventional moving principle.

Initially, the individual resides with their partner in an apartment before making the decision to invest in a house. Upon the arrival of their first child, the couple typically seeks additional space and purchases a single-family home. They remain in this residence as they have a second child and continue to inhabit it throughout their children's formative years. Once the children have moved out, the parents, now reunited as a couple, continue to reside in the same dwelling. Over time, they grow older as a couple, or the main individual loses their partner. It is only when the main individual becomes too frail to live alone that they move into a care home.

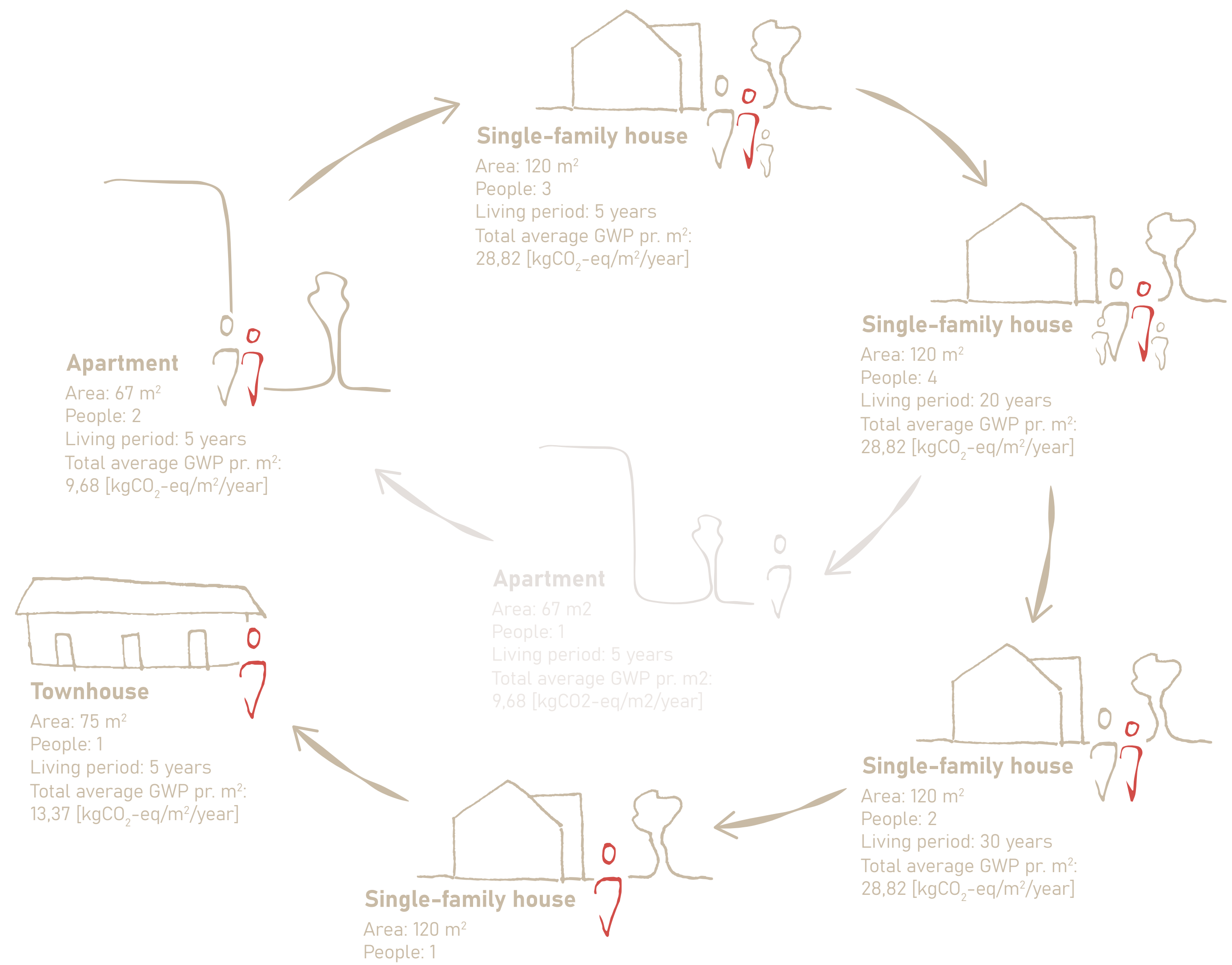
As can be seen in the illustration, a family generally lives for a long time in the same single-family house under the conventional moving principle, which results in little to no renovations of the house over time.

Illustration 55 presents the number of years and people residing in each typology, along with the corresponding areas of the general typologies and their respective climate footprints.

Given the assumption of minimal or no renovation occurring within the framework of the conventional moving principle, the average operational climate footprint prior to renovation (established in the previous investigations) is utilised for this calculation.

As demonstrated, the conventional moving principle leads to a high climate footprint across the various moving scenarios, primarily due to the absence of renovations. The following section will introduce an alternative moving scenario, centred on the implementation of the housing rotation principle.

Living period	**Total average global warming potential**	
[year]	**[kgCO_2-eq/m²/year]**	**[kgCO_2-eq/m²]**
5	9,68	48,4
5	28,82	144,1
20	28,82	576,4
30	28,82	864,6
5	28,82	144,1
5	13,37	66,85
	Sum:	1.844,45
	Average pr. year:	**26,35**



Ill.55: Diagram conventional moving principles

housing rotation principle

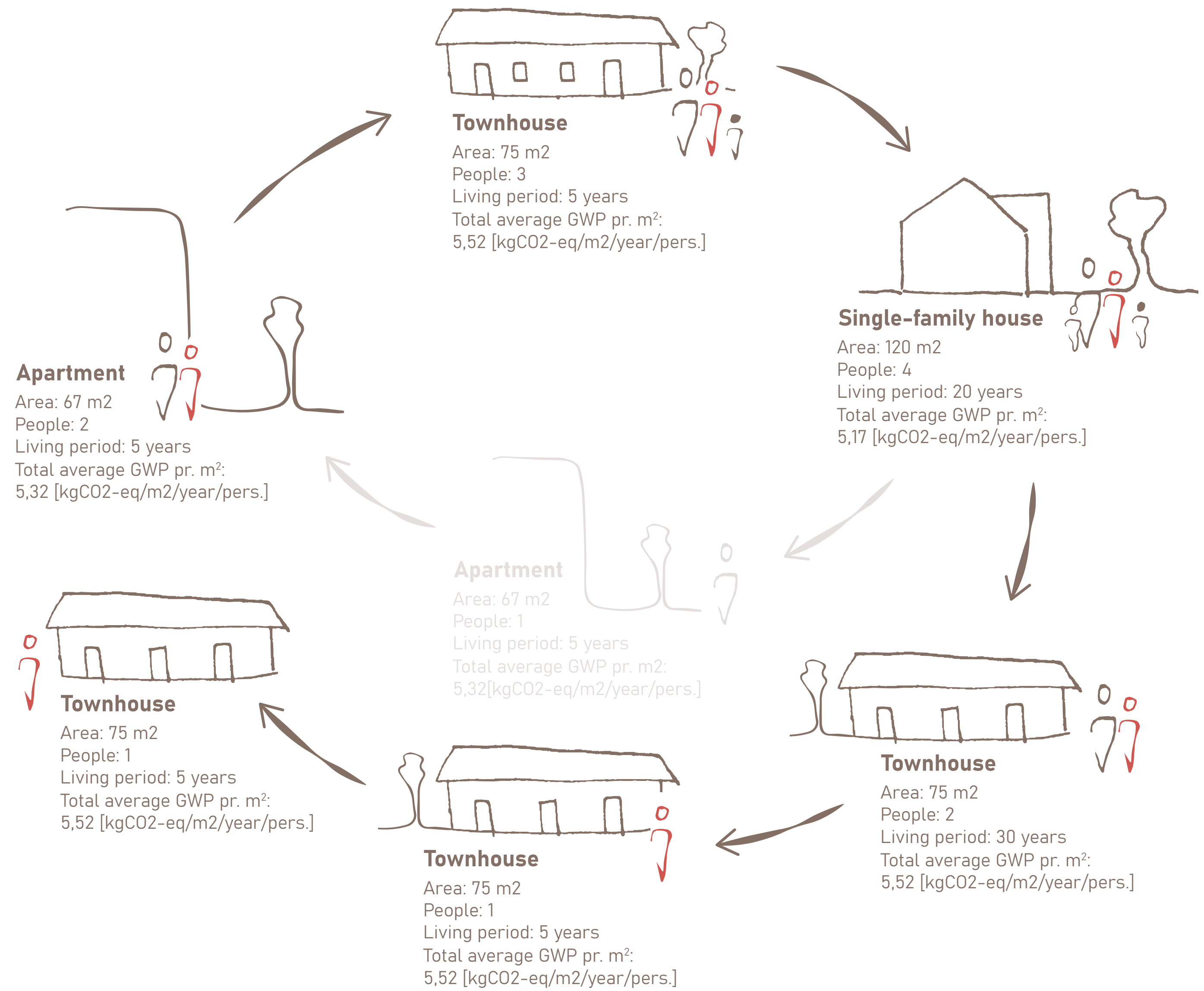
Alternatively, a new moving scenario is developed by implementing the housing rotation principle, as illustrated in illustration 54.

In this alternative moving scenario, the main individual initially resides in an apartment with their partner. Upon the arrival of their first child, they seek a larger living space and chooses a townhouse, thus avoiding an immediate investment in a single-family home. As their family grows with the addition of a second child, they again require more space and choose to purchase a single-family house, where they remain throughout their children's upbringing. Following the departure of their children, the parents, now a pair once more, downsize to a smaller townhouse that better aligns with their evolving needs. They continue to reside in this dwelling until they reach an advanced age, at which point they transition to an elderly care facility.

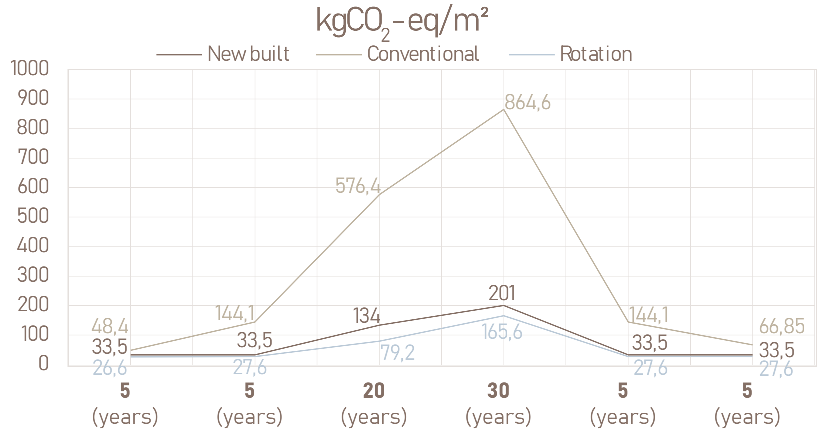
This moving principle facilitates the main individual's transition into more suitable housing typologies that correspond to their evolving family circumstances throughout their lifetime. By encouraging more frequent moves, this approach ensures that the housing typologies undergo renovations at regularly, leading to a reduction in the overall climate footprint.

The results of the building rotation principle, alongside the conventional moving principle, will be further analysed and compared in the following section.

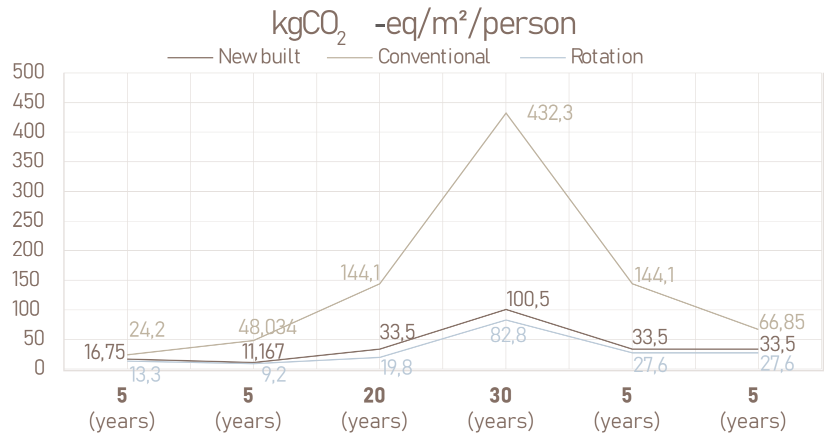
Living period	Total average global warming potential	
[year]	[kgCO$_2$-eq/m²/year]	[kgCO$_2$-eq/m²]
5	5,32	26,6
5	5,52	27,6
20	5,17	103,4
30	5,52	165,6
5	5,52	27,6
5	5,52	27,6
	Sum:	378,4
	Average pr. year:	**5,4**



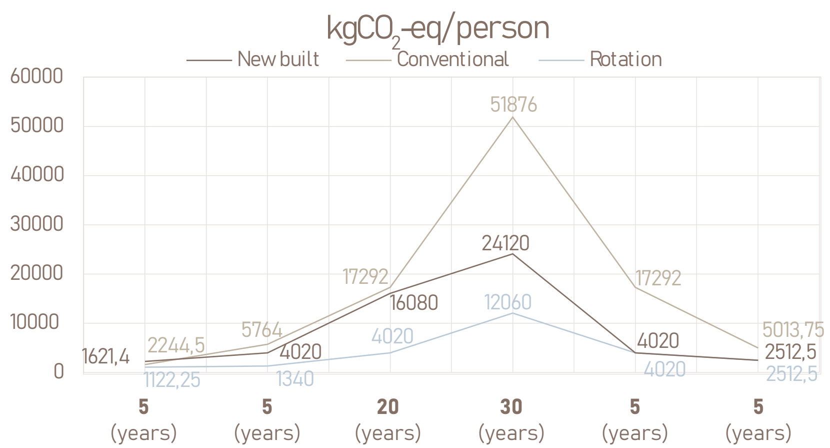
Ill.56: Diagram buidling rotation



Ill.57: Comparison graphs I



Ill.58: Comparison graphs II



Ill.59:Comparison graphs III

conclusion & learnings

To conclude the investigation, a comparison is made between the results of the conventional moving principle and the housing rotation principle. Additionally, the principle of new construction is included in the comparison, using the same baseline framework as the conventional moving principle. See Appendix 12: Calculations for rotations for detailed calculations. In this case, the results of the typologies before renovation are replaced with the new requirements set for 1st July 2025, which demands a climate footprint of 6,7 kgCO2-eq/m²/year. (Trafikstyrelsen, n.d.)

The diagrams (ill. 57-59) present the climate footprint of the main individual across the different moving principles over a total period of 70 years, as outlined in the previous section. Each diagram illustrates the various outcomes and facilitates a comparison, ultimately concluding which moving principle is most effective in minimising the overall climate footprint.

The first diagram (ill. 57) compares the climate footprint per square metre for three moving principles over different time periods. As illustrated, the conventional moving principle exhibits a significantly higher climate footprint compared to both the new build and housing rotation principles, primarily due to its high operational energy demand and lack of renovation. Another noteworthy observation in this diagram is that the housing rotation principle performs the best, despite the inclusion of an embodied climate footprint associated with renovations. This suggests that even with the new climate footprint requirements coming into effect after the 1st of July this year, the housing rotation principle—through the renovation of existing buildings—results in a lower overall climate footprint over the 70-year period.

Illustration 58 presents the climate footprint per square metre and person for the different moving principles over various time periods. When compared to the first diagram (ill. 57), this diagram demonstrates a decrease in climate footprint during time periods where the number of people living together increases. This indicates that a larger household or assembly of people leads to a reduction in the total energy consumption per individual, highlighting the potential efficiency of shared living in terms of climate impact.

The final diagram (ill. 59) illustrates the total climate footprint of the different typologies' areas, divided by the number of people living together. As shown, the conventional moving principle has the highest climate footprint, primarily due to its high operational energy demand and the fact that fewer people live in larger homes for extended periods of time. The new-build principle performs better than the conventional moving principle, due to the new regulations that require a significantly lower climate footprint per square metre. However, the housing rotation principle emerges as the most optimal, as it ensures that individuals move into typologies that better match their family size while simultaneously promoting renovations when relocating to existing dwellings.

This investigation highlights the significance of implementing the principle of housing rotation in small cities to facilitate the development and renovation of existing housing. As the findings demonstrate, energy-efficient renovations of existing buildings result in a lower climate footprint compared to the new requirements for newly built properties. Furthermore, an important conclusion drawn from the investigation is the value of increasing the number of people living in smaller dwellings.

Ill.60: Drawing courtyard entrancr

design specification & programming

Building program | Project thesis | Design Parameters

Building upon the historical context, site analyses of Råby, and the principles of housing rotation, this section seeks to specify and articulate the project's direction. The aim is to synthesise the insights gathered in the previous sections in order to formulate a building program and a set of design parameters that will inform and support the design process.

building program

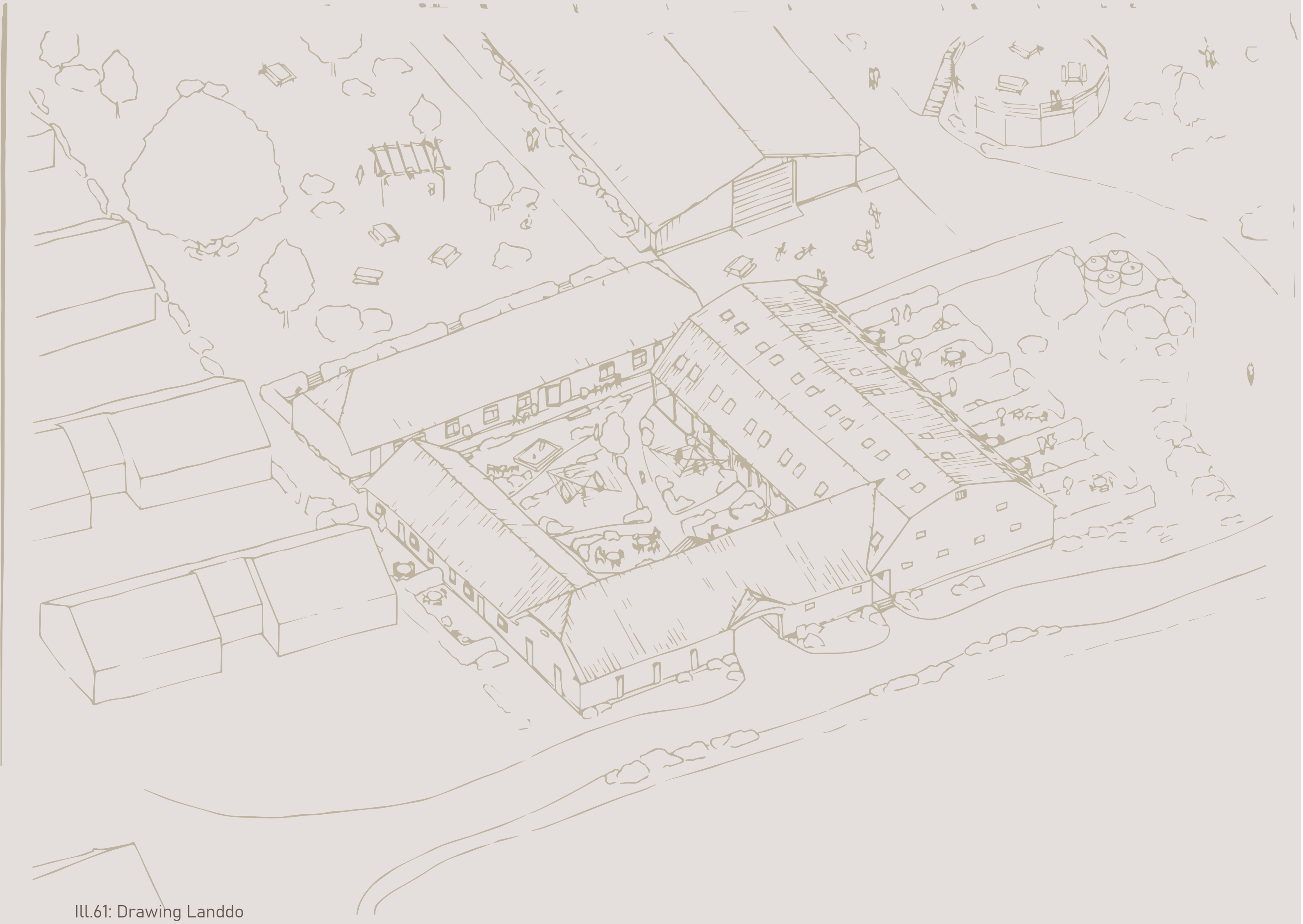
Based on the selected users and the decision of making public housing dwellings, a building program has been developed. This program functions as a guiding framework in which the various aspects of the dwelling are organised and scheduled, providing a comprehensive overview. It serves to support the design process of the cattle farm's transformation by ensuring that the specific requirements and characteristics of each individual space are considered and integrated into the architectural proposal.

The building programme is based on the principles of the three-room dwelling (see page 140 in the Design process for further elaboration), supplemented by technical specifications such as daylight access and natural ventilation requirements.

To ensure a realistic building programme, a study of floor plans provided by the interviewed housing association was conducted.
These plans, developed by N+P Arkitektur for the "Fælleden" project in St. Restrup (N+P Arkitektur, 2021), offered valuable insight into room dimensions and spatial layouts. The reference program, derived from this material, can be found in Appendix 13: Reference programme.

With all of these decisions and requirements in place, the project thesis could be formulated. This thesis consolidates the knowledge and insights gained from the preceding sections into a single, cohesive statement, which served as the foundation for initiating the design phase.

Building Program								
	functions	quanity	size	nat.light	nat.vent	Access to outside	min. area	max. area
unit	*description*	*amount*	*m²*	*yes/no*	*yes/no*	*yes/no*	*m²*	*m²*
The three room dwelling		**(10-15)**	**65-100 m²**				**65 m²**	**100 m²**
dwelling	kitchen	*1*	*15-20m²*	*yes*	*no*	*-*	*15m²*	*20m²*
	living space	*1*	*15-20m²*	*yes*	*yes*	*yes*	*15m²*	*20m²*
	bedroom	*2*	*10-12m²*	*yes*	*yes*	*-*	*10m²*	*12m²*
	toilet/bath	*1-2*	*4-18m²*	*no*	*no*	*no*	*8m²*	*12m²*
	entrance	*1*	*4-6m²*	*no*	*-*	*yes*	*4m²*	*6m²*
	storage	*2-3*	*2-4m²*	*no*	*no*	*no*	*2m²*	*4m²*
	technical	*1*	*1m²*	*no*	*no*	*no*	*1m²*	*1m²*
						total	***67m²***	***91m²***
common	kitchen	*1*	*15-25m²*	*yes*	*no*	*yes*	*15m²*	*25m²*
	dining space	*1*	*25-35m²*	*yes*	*yes*	*yes*	*25m²*	*35m²*
	laundry space	*1*	*10-15m²*	*no*	*no*	*no*	*10m²*	*15m²*
	toilet	*2*	*6-8m²*	*no*	*no*	*no*	*6m²*	*8m²*
						total	***56m²***	***88m²***
outdoor	parking	*1,5 pr unit*	*-*					
	green space	*(1-2)*	*-*					
	waste	*1*	*-*					

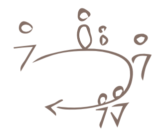


Ill.61: Drawing Landdo

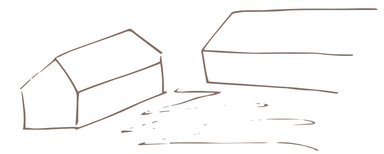
project thesis

This thesis explores the **transformation** of **Danish agricultural buildings**, based on a cattle farm in Råby, into **new building structures** that **integrate** with and **respect** the surrounding **village**. By applying principles of **housing rotation**, the study seeks to ensure **environmental** and **social sustainable development** while simultaneously preserving the **cultural** and **historical** significance of **rural architecture**.

VILLAGE

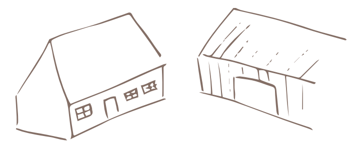


The design solution must ensure greater diversity in residents of the village through the concept of housing rotation.

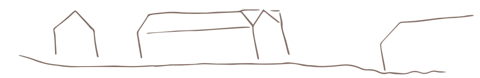


The design solution must embrace Råby's local life and support it by implementing elements that facilitates both residents of Landbo and external users.

CULTURAL & HISTORICAL



The design solution must preserve the existing structures of the cattle farm to visualise and respect the development and history of agricultural buildings.



The design solution must embrace the village profile of Råby and the rural landscape.

design parametres

To support the project thesis, a series of design parameters have been established to guide the process and clarify specific requirements. These parameters are informed by the theoretical foundations and themes explored in this report, as well as the identified needs of the users, supported by insights gained from interviews. As the project has evolved, these parameters have been revised and refined to reflect new insights and developments.

Ill.62: Drawing entrance

presentation

Fællesskabet Landbo | Råby | Zones | Courtyard
Exterior | Common house

From the various theories, topics and investigations the next section will present the design solution for this thesis. The solution will be presented through different architectural drawings, such as plans, sections and elevation along with renders.

Fællesskabet **Landbo**

Within the rural land of Denmark, Fællesskabet Landbo appears by the village pond in Råby. Landbo is a new residential area that offers community-based public housing for both existing residents and newcomers. By providing rental housing opportunities, the concept of housing rotation is accommodated in Råby, supporting development while securing a sustainable future for the village. The transformation of the cattle farm contributes to the preservation of the farm's historical significance and highlights the village's cultural heritage.

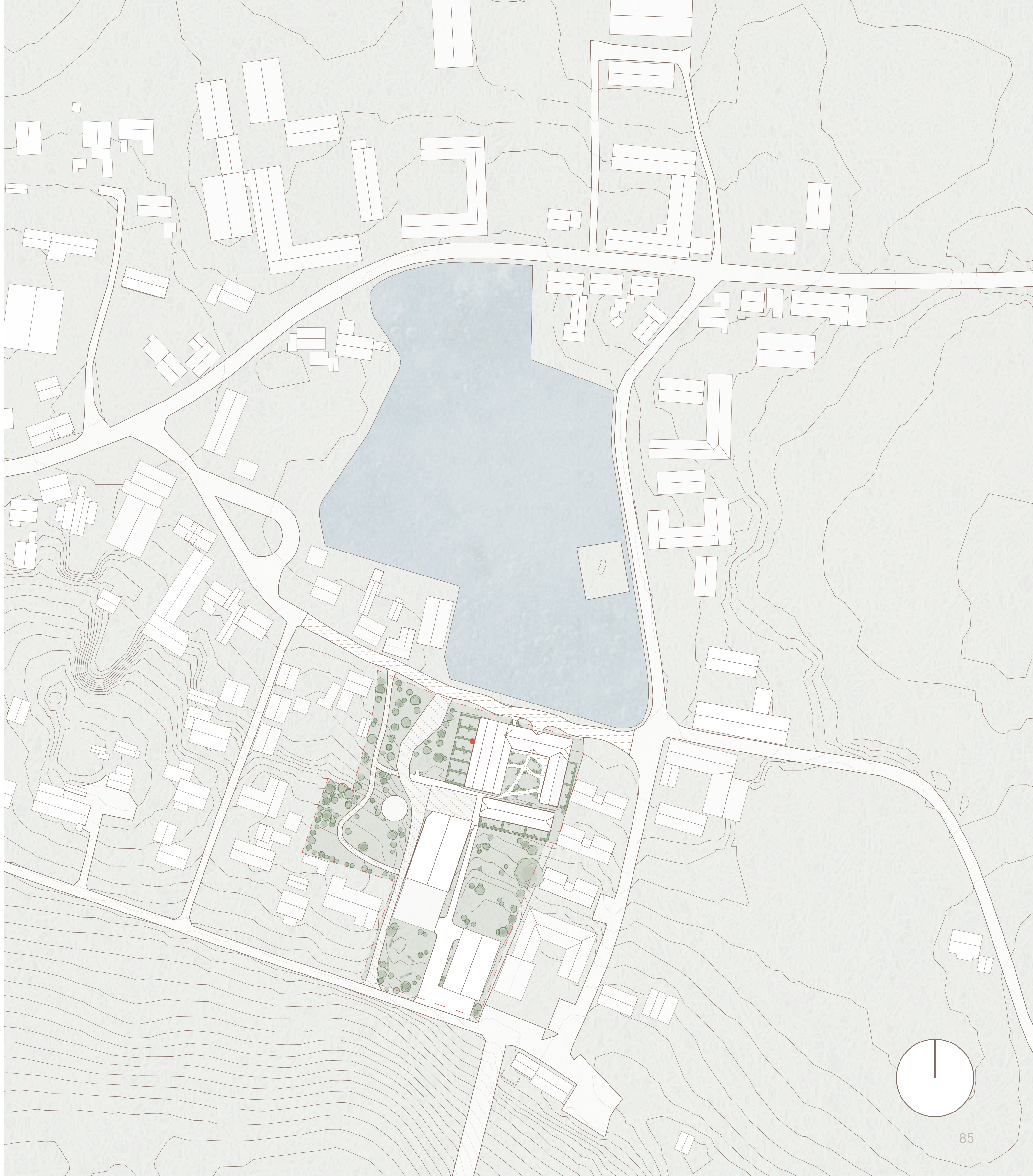
Situation plan

As presented in the situation plan, Landbo is located towards the south in Råby. The northern façade of the four-wing farm is oriented directly towards the village's most prominent landmark: the pond. With the placement of the entrance gate, a direct and easily accessible connection between Landbo and the surrounding village are ensured.

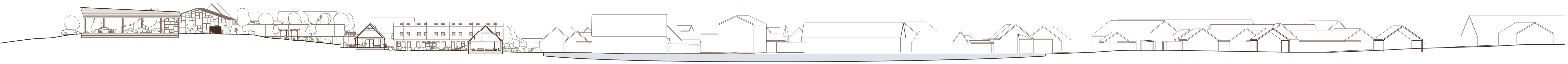
The public park structure established at the western end of Landbo creates a link to the village, inviting Råby's residents to make use of the area, with convenient access via a gravelled road.

With the placement of Landbo in the centre of Råby, the design proposal ensures an important role within the city image and an optimal place for outdoor gathering the residents of Landbo with the residents of Råby.

Ill.63:Situation plan 1:2000



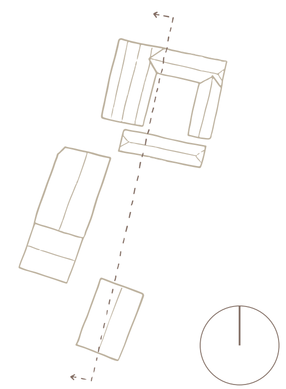
Ill.64: Render courtyard



Råby

Ill.65: City section 1:1000

The village of Råby is located in an undulating landscape, where the outer edges of the settlement rise and continue to increase towards the central village pond. Fællesskabet Landbo is positioned at the village's edge, where the terrain reaches its highest point. Due to the varying levels within the site, several distinct zones are created, supported by both the design and programming.



Masterplan

Ill.66: Masterplan 1:500

Ill.67: Urban render

Ill.68: Entrace render

zones

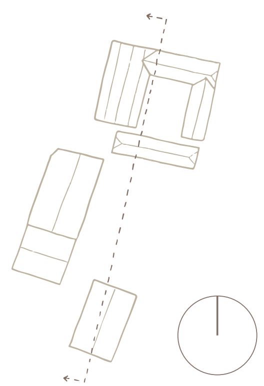
Section

Ill.69: Site section 1:500

The design solution, fællesskabet Landbo, offers a variety of opportunities for both the residents of Landbo and the wider local community of Råby. At the northern end, a four-wing farm building has been transformed into public housing units arranged around an internal communal courtyard, creating a more private zone for Landbo's residents.

Behind the four-wing structure another green zone is defined with outdoor area for residents to use for barbecues and social gatherings, which is an extension of their own private garden. This zone also includes a workshop building accessible to both Landbo residents and the wider village.

At the southern hilltop, a semi-public area includes a greenhouse for Landbo's residents and an open structure for parking, which can also be used for larger events such as summer parties for the local community of Råby.

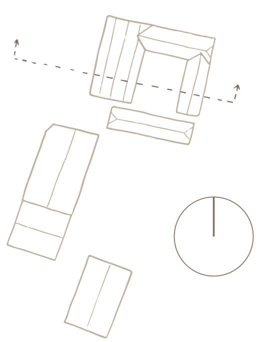


Plan render

Ill.70: Plan render

courtyard

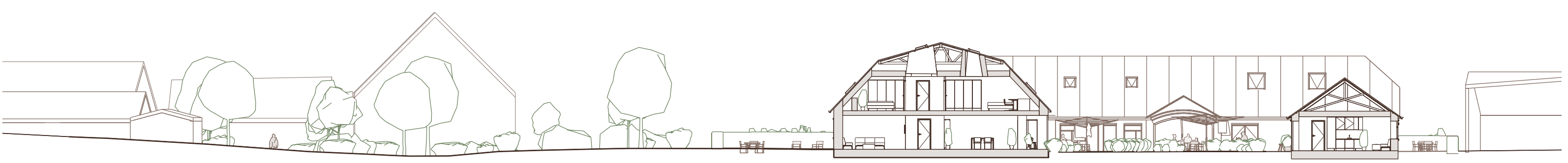
Section



The four-wing building has been transformed into a public housing area. Its square configuration allows for the creation of an internal communal courtyard, which residents of Landbo can use for social interaction within their small community. The courtyard includes a green space designed for various types of use. Small seating areas provide opportunities for social gatherings, while a sandpit offers a place for young children to play near the residential units.

Shared drying racks for laundry transform a typically individual task into a communal activity, encouraging further social engagement among residents. The patios in front of each dwelling unit, defined by a change in surface material, serve as semi-private spaces between the private homes and the semi-public courtyard, offering places for informal interaction.

Altogether, the housing units of Landbo fosters a social community within the village of Råby and acts as a physical and social threshold between the two.



Ill.71: Section 1:500

Ill.72: Courtyard render

Plan

Ill.73: Plan wing farm 1:200

Units	Area	Units	Area	Units	Area	Units	Area
West building	**[m²]**	**South building**	**[m²]**	**East building**	**[m²]**	**North building**	**[m²]**
Gross area	118	Gross area	73	Gross area	67	Common house gross	110
Netto area	98	Netto area	62	Netto area	56	Common house net	91
Garden	39	Garden	36	Garden	37	Apartment gross	31
A Living room	18	**G** Entrance	4	**M** Bedroom	11	Apartment net	23
B Passage	3	**H** Kitchen	6	**N** Bedroom	9	**S** Bathroom	5
C Toilet	4	**I** Living room	22	**O** Living room	19	**T** Room	18
D Kitchen	5	**J** Bathroom	5	**P** Entrance	4	**U** Common room	65
E Dining room	13	**K** Bedroom	11	**Q** Kitchen	6	**V** Toilet	3
F Entrance	4	**L** Bedroom	10	**R** Bathroom	5	**W** Toilet	4
						X Laundry	4
						Y Kitchen	19

Plan

Ill.74: Plan wing farm, 1.floor 1:200

Units	Area	Units	Area
West building	**[m²]**	**North building**	**[m²]**
A Bedroom	14	**G** Patio	25
B Passage	4		
C Bathroom	4		
D Chamber	11		
E Chamber	9		
F Bedroom	21		

housing units

Ill.75: Render patio

Ill.76: Render living space

Within the four-wing farm, a row-house typology with various housing units has been integrated to provide a diverse range of housing options within Råby. The dwellings follow a three-room principle, ensuring a living room and two separate rooms. These rooms can be adjusted in both depth and width to suit the users' needs.

Each unit also includes a kitchen with integrated storage and full domestic appliances, along with a bathroom and an entrance that offers additional storage space, meeting the needs of the residents.

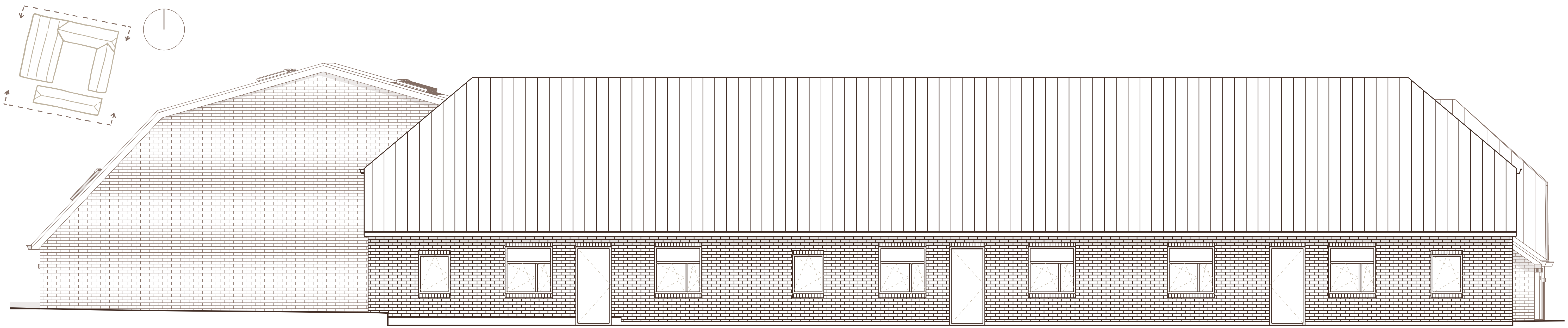
Ill.77:Housing unit render

Ill.78: Housing unit render

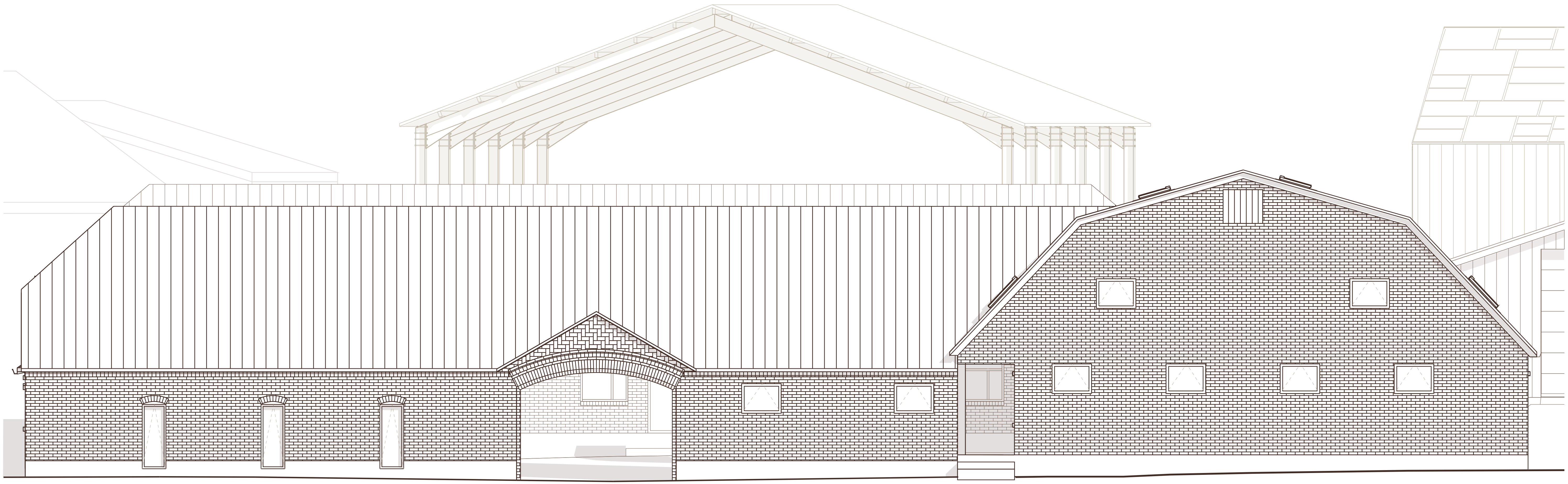
The dwelling units are adaptable, allowing residents to adjust the inner walls in the bedrooms to suit their individual needs. For example, an elderly couple could have a larger bedroom and a smaller office instead of two evenly sized bedrooms, or a family, living in the two-storey dwelling unit, could have two separate chambers as children's rooms.

Ill.79: Housing unit render

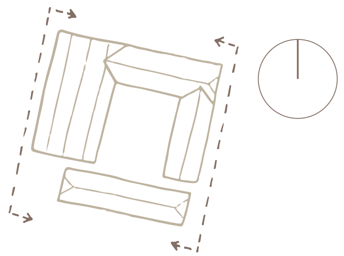
Ill.80: Housing unit render



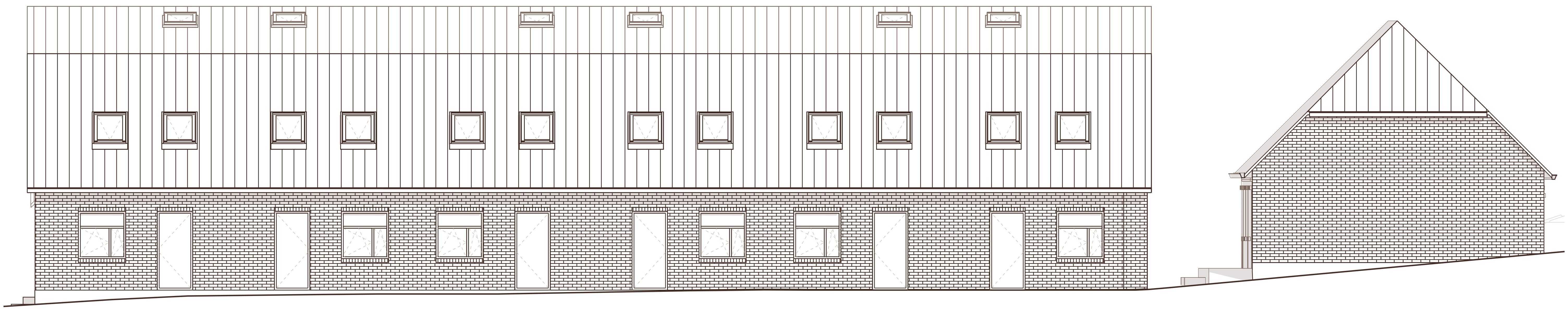
Ill.81: Elevation, south 1:100



Ill.82: Elevation, north 1:100



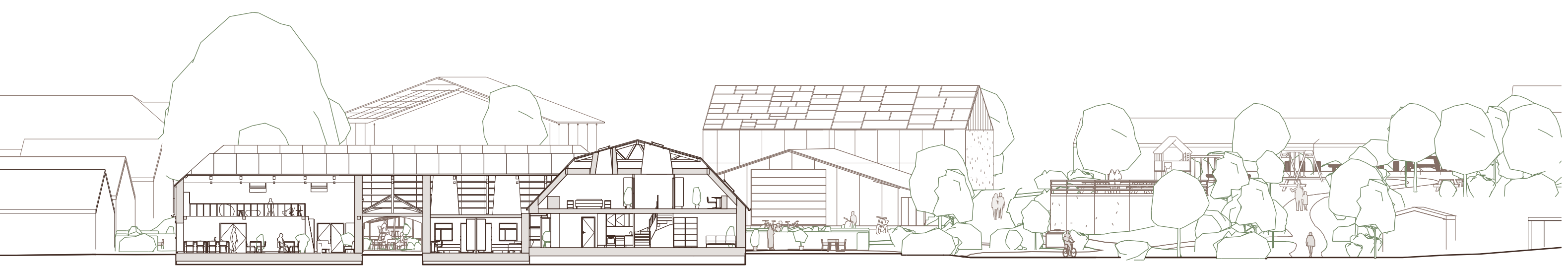
Ill.83: Elevation, east 1:100



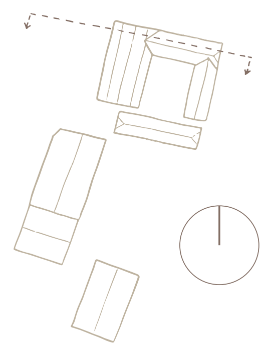
Ill.84: Elevation, west 1:100

common house

Section



Ill.85:Section comunity 1:500



Ill.86: Render common house

exterior

In addition to implementing a public housing area within the farm, Landbo also offers a variety of activities to engage the community both within Landbo and the local community of Råby.

At the centre of the site, a cattle barn has been transformed into a workshop and storage space, for the residents of Landbo and Råby to use for social interaction, through repairing items and practising hobbies together in a shared environment.

At the southern end, the two existing machinery barns have been transformed into a large greenhouse, with additional outdoor space featuring raised beds, where residents of Land-bo can grow plants and vegetables together. This area also includes an open structure for everyday parking, which can be used by the residents of Landbo, as well as a space for the residents of Råby to arrange larger events and gatherings, such as summer parties. The open construction also accommodates solar panels, which contribute to on-site energy production and complement the building's industrial character.

Ill.87: Render exterior

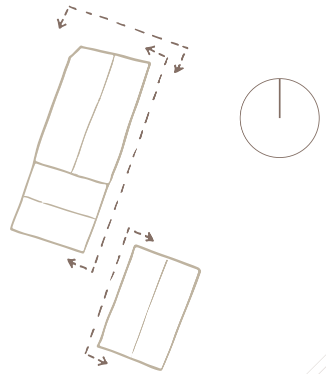
Plan

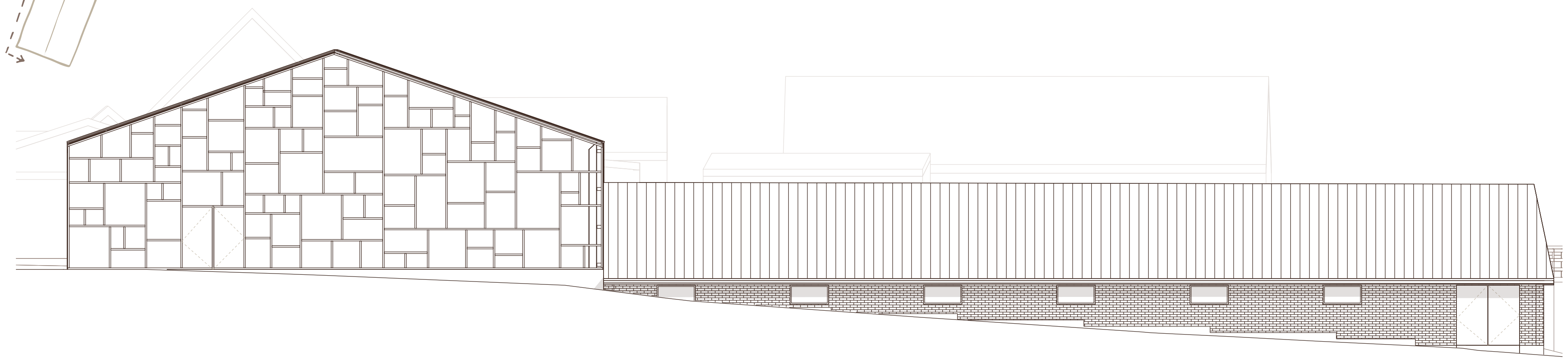
Ill.88:Plan utility buildings 1:400

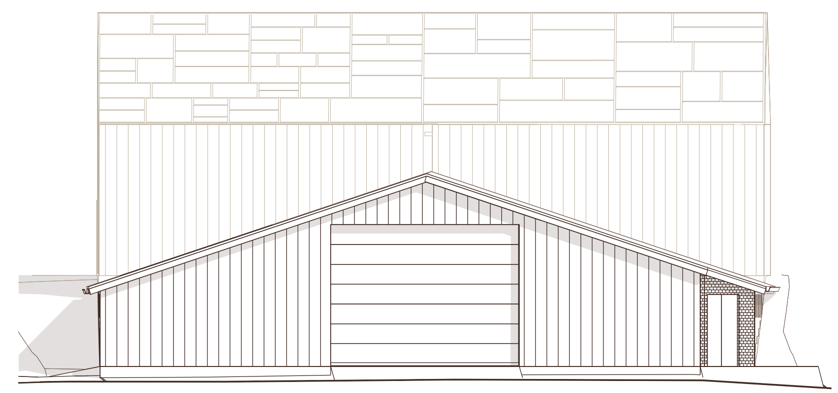
Units	Area	Units	Area	Units	Area
Workshop	**[m²]**	**Green house**	**[m²]**	**Open structure**	**[m²]**
Gross area	507	Gross area	300	Gross area	382
Netto area	578	Netto area	288		
A Workshop	271				
B Storage	13				
C Passage	13				
D Freezer room	19				

Ill.89: Render green house

Ill.90: Render green house

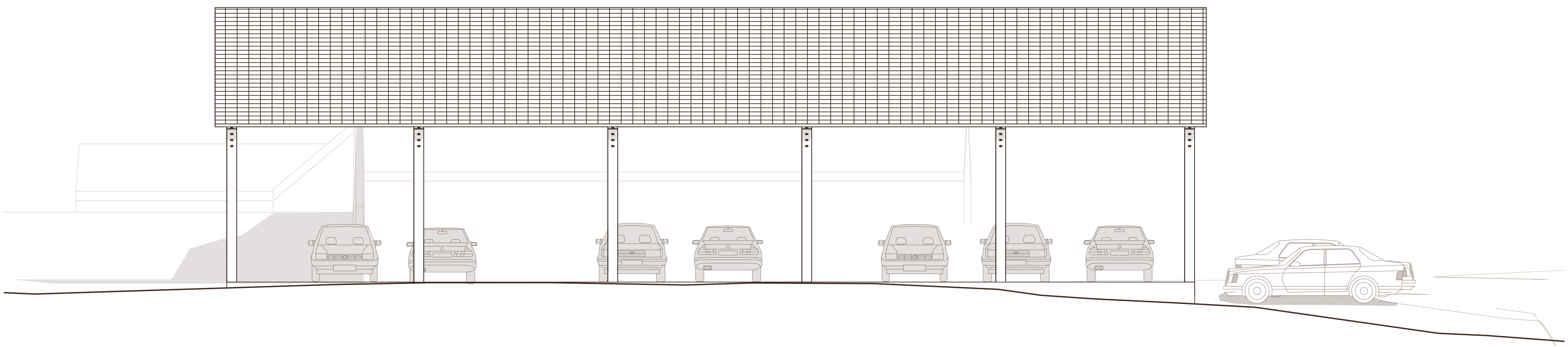






Ill.91: Elevation utility buildings, east 1:200

Ill.93: Elevation utility buildings, north 1:200



Ill.92: Elevation utility buildings, west 1:100

Ill.95: Drawing outdoor space

design process

Programming & circulations | Plans | Exterior & surroundings |

Facades & openings | Materials & aesthetics

With the design solution now presented, the following section will outline the process that led to its development. The design has evolved through an iterative approach, in which sketching, analysis, and synthesis formed a non-linearly process. Consequently, this section is structured into a series of chapters, each focusing on specific, isolated aspects of the design to provide a clearer understanding of its progression.

programming & circulation

The first part of the design process section aimed to investigate the programming and general principles of circulation in terms of functionality and social connections. This were primarily examined from a plan perspective, providing an overview that simplified the process. The investigation was based on information from the previous site analysis, along with the project's specifications, such as the building program and design parameters.

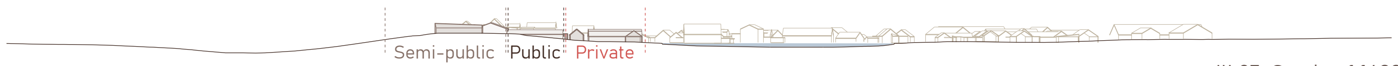
It is important to note that the process has been iterative, with several iterations occurring simultaneously. For clarity, the process will be presented in different chapters, each highlighting specific elements of the design to visualise the project's development. The first chapter covers the programming and zoning of the site. The next chapter will focus on the physical connection strategies that support the different zones. Following that, a chapter will explore the seasonal circulation of the programming will be presented. Together, these chapters illustrate the project's process of shaping the general programming and zoning aspects.

Ill.96: Render door

Programming & zones

Along with establishing the building program (see page 79) the different principles of placing the various functions into the many building masses of the cattle farm took place. With the strategy of respecting the existing building masses derived from the SAVE-analysis the different functions, from the building program, were forced and fitted into the existing forms of the farm. Therefore, the dwellings were placed in the wing farm buildings, due to its more fitting dimensions, and the other functions such as activities and cold functions was located in the farm's utility buildings. At the beginning of the designing phase a brainstorm of different functions and their placement were conducted to examinate the different potential uses of the site. Along with implementing the users, the functions were reduced, and the programming of the farm was initiated.

For this section, the site has been divided into three distinct zones: public, semi-public, and private (see ill. 97). These zones are primarily defined by the slope of the terrain and the positioning of the existing buildings within it. The zoning also played a key role in determining the placement of the various functions and activities of the farm.



Ill.97: Section 1:14000

Result

Ill.98: Iterations

The western part of the site is designated as the public zone, which connects the city of Råby to the farm through various outdoor activities that invite external users into the area. These activities are oriented towards children, families, and the elderly, providing opportunities for leisure and recreation. The transformation incorporates park-like elements, contributing a green space to the city that serves as an outdoor meeting area for the residents of Råby. The semi-public zone is the largest and most prominent area of the site, featuring a cold building that houses a workshop and repair space where residents of Landbo can pursue various hobbies. This space is also open to external users, such as teenagers from the city, providing a space for after-school activities or hobby-based gatherings. Additional structures within the semi-public area include an open greenhouse for residents and an adaptable open garage suitable for hosting various outdoor events. Furthermore, the semi-public zone includes outdoor spaces that extend the residents' private gardens, fostering opportunities for social interaction and development.

Finally, the different housing units of Landbo is located in the private zone towards the north, due to the existing structure's orientation towards each other and the building sizes, these are optimal for dwellings.

Private

Ill.99: Private zone programming

Semi-public

Ill.100:Semi-public zone programming

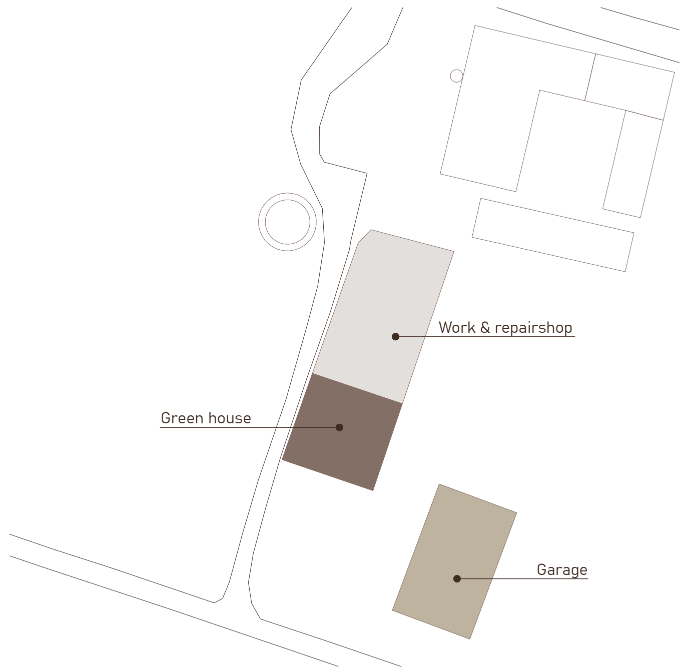
Public

Ill.101: Public zone programming

Yearly & seasonal usages

Focusing on the utility buildings in the semi-public zone, the functions within them were determined by the seasons. This decision stemmed from the choice not to re-insulate the buildings, which leads to a cold building mass during the winter months. While this limited certain functions, it was optimal for others. These functions allowed the buildings to undergo minimal transformation with only small adjustments, as there were no need for re-insulation or material changes. This approach, with minimal transformation, provided a significant advantage in terms of lowering the global warming potential.

This section investigated the yearly and seasonal usage and functions of the buildings. The three cold utility buildings, which are the work and repair shop, the greenhouse, and the garage, are highlighted on Illustration 102. On illustration 103 the accompanying annual diagrams illustrate the seasonal usage of these buildings. In general, the buildings are primarily used for storage during the winter months, allowing residents of Landbo to store outdoor and hobby equipment. External residents of Råby can also make use of this cold, yet dry, storage space during the winter, where they can store larger objects such as caravans or boats. By removing all metal sheet facades and transforming it into an open construction, its industrial expression will be enhanced, while also ensuring an open and flexible area that is roof-covered. The building's location to the south, atop the hill, provides excellent potential for the installation of solar panels to generate electricity on-site and improve the energy demand of the other buildings. Since the current roof consists of fibrecement with asbestos, a new roof with integrated solar panels will be installed (ill. 103).



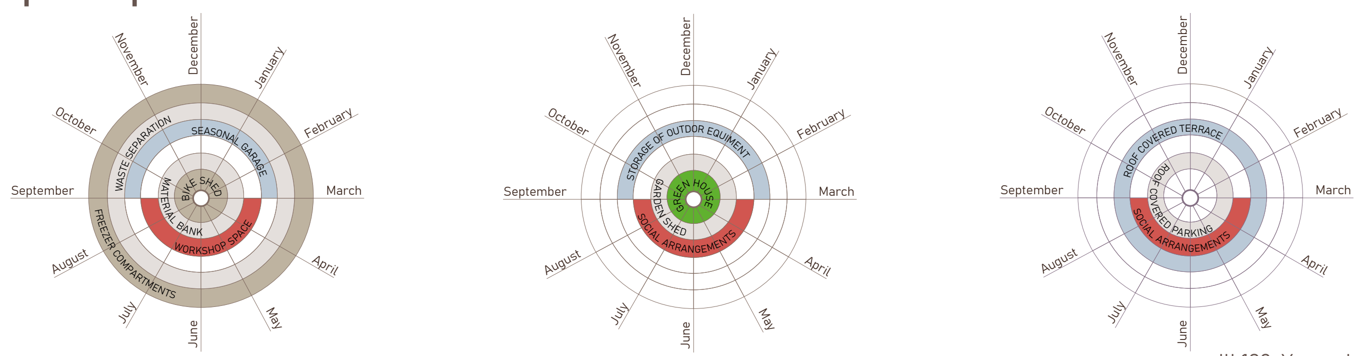
Ill.102: Map utility buildings

The work and repair shop provides a workshop space for hobby projects for users of all ages, such as carpentry, metalworking, and similar activities. In addition, the space is equipped with a wood and metal bank to support these projects.

The greenhouse, located on the opposite side of the workshop building, serves primarily as a communal space for the residents of Landbo, where they can enjoy and grow various fruits and vegetables. During the coldest winter months, the space will function as a storage area for the residents' outdoor equipment. To reduce the global warming potential of this transformation, the glazed areas will consist of re-used windows from the site and external material banks. Appendix 15: Window amount provides an overview of the current buildings with glazed areas that will be demolished or replaced by improved windows. This total amount of glass will be re-used in the facades of the greenhouse, as shown in Illustration 104. The remaining facades and roof will be completed with external re-used windows, for example, from the single-family, farm, and townhouses in Råby, which, through the concept of housing rotation, will undergo renovation.

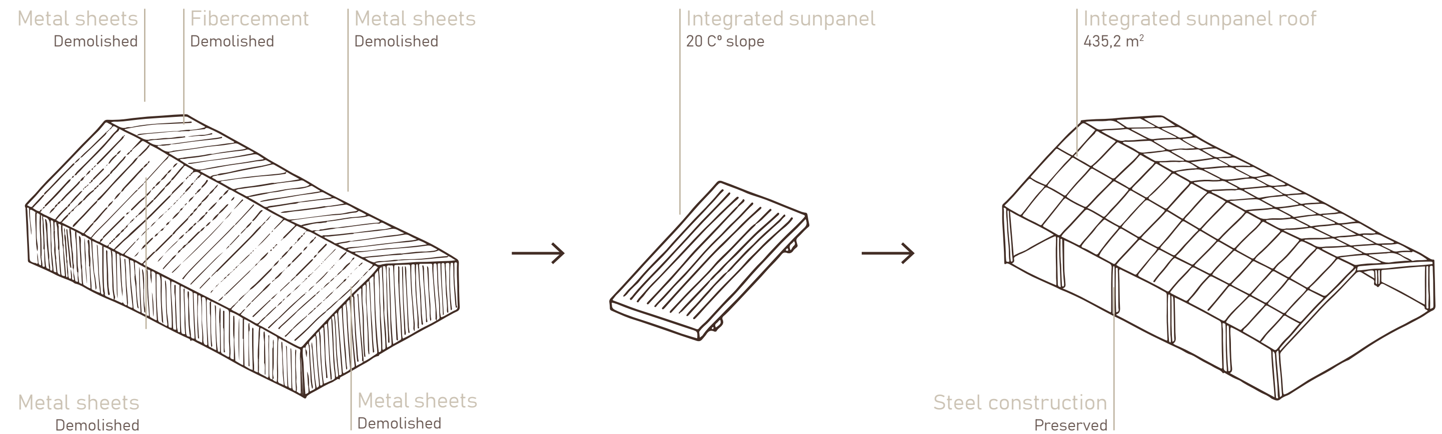
Overall, the utility buildings offer Landbo new activities and enhance the quality of the site. Through the transformation, the buildings take on a new purpose in terms of functionality, thereby extending their lifespan without the need for significant alterations to the building volumes.

Work & repairshop **Green house** **Garage**



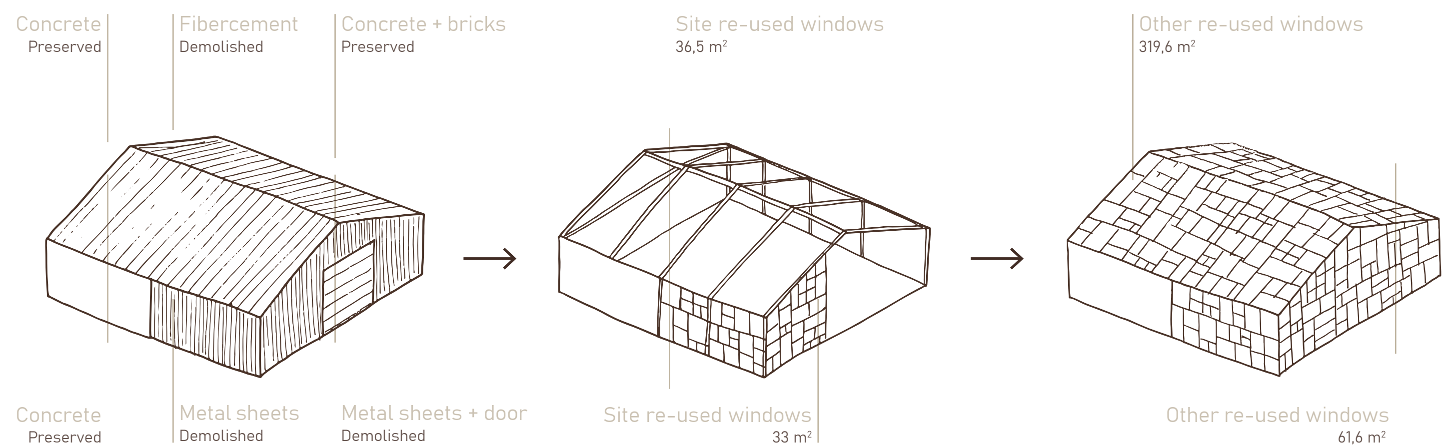
Ill.103: Year wheels

Garage



Ill.105: Garage transformation

Green house



Ill.104: Green house transformation

plans

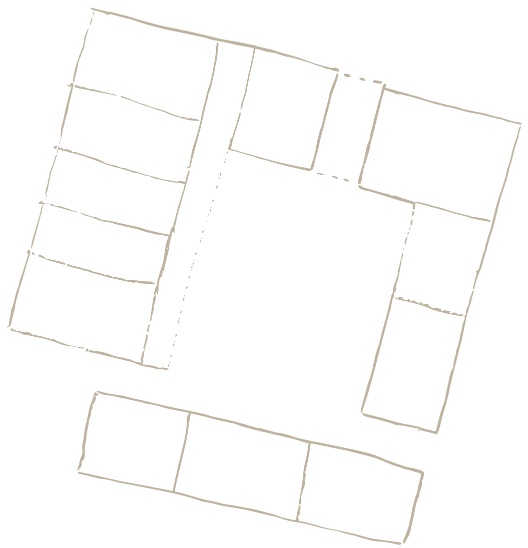
After the various functions and activities have been allocated to the site, the next section investigated the layout of the plans, primarily focusing on the housing units. Multiple iterations of the plans were developed throughout the process. This section will present a series of simplified principles from the most influential iterations that have shaped the final design outcome. In addition, the section will also present two studies conducted to better understand the site and housing type for the plans' layout.

Ill.106: Render living space

Building dimensions

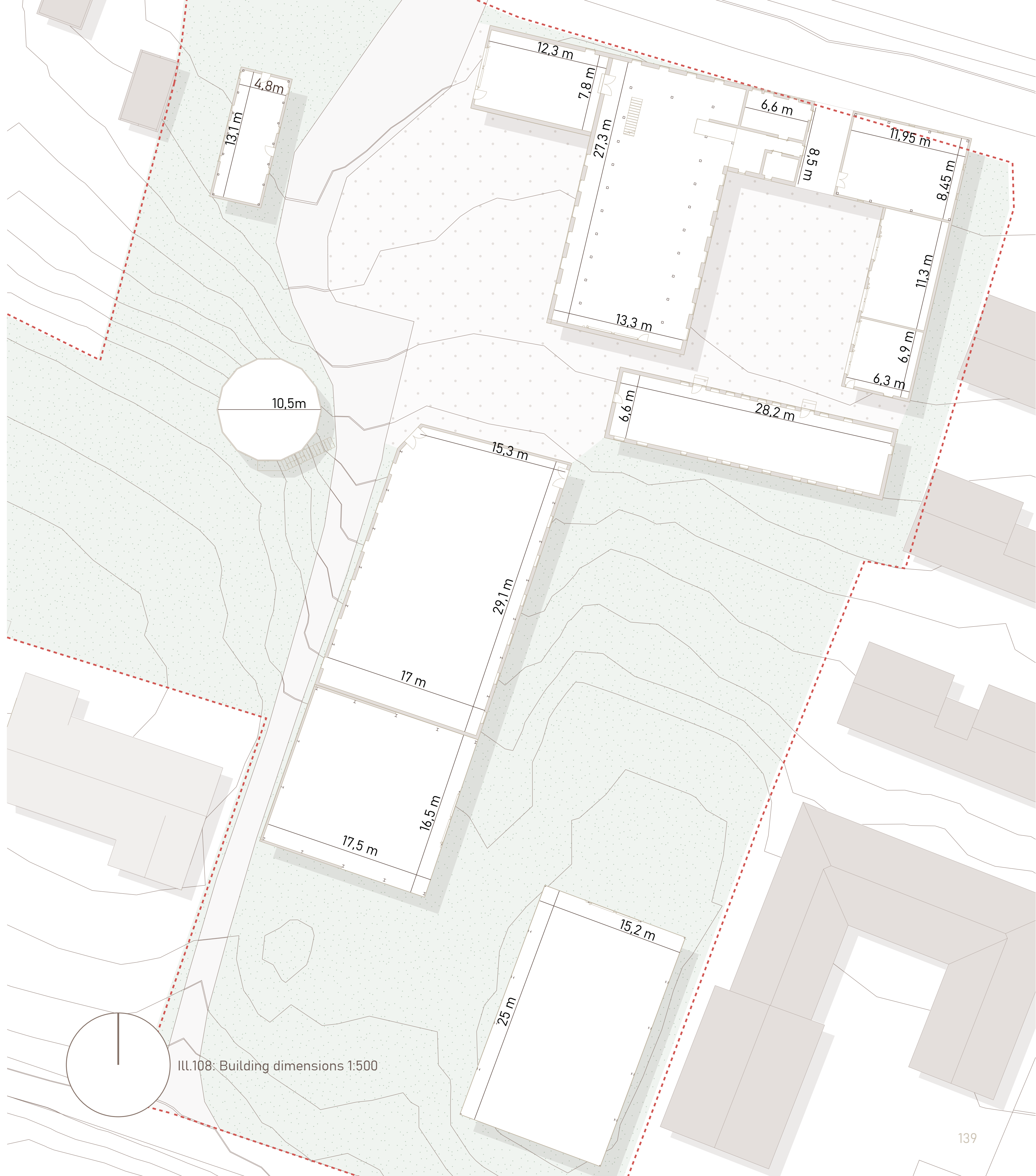
In the early phases of sketching and analysing the site, the dimensions of the buildings were investigated to understand the potential and limitations of their forms. Initially, housing units were considered for all of the existing building masses; however, after further investigation, this approach was reconsidered. Some buildings were simply too wide or too long to accommodate dwellings, while others were partially buried in the terrain, requiring significant intervention and alteration of the natural landscape, which was not desirable. As a result, alternative functions and activities were placed within these buildings, as detailed in the previous section on programming and circulation.

Three of the buildings located to the north were ideally proportioned to accommodate housing units. These include the living wing of the farm, the garage, and the old grain storage barn, all of which were well-suited for transformation. In addition to their dimensions and proportions, their placement and relationship to each other created an optimal layout for an inner courtyard, enhancing social interaction among the residents. To complete the courtyard, the old cattle barn to the west needed to be incorporated into the housing zone. Like the other utility buildings on the farm, the cattle barn presented challenges due to its dimensions. The building was 13 metres deep and over 27 metres long (ill. 108).

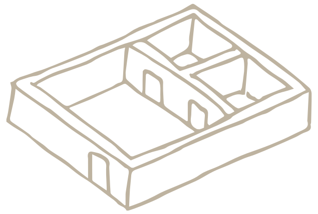


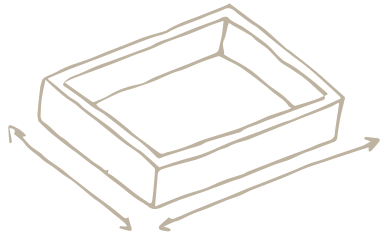
Ill.107: Change of depth

To ensure a functional dwelling with adequate natural daylight, the outer wall on the east side was moved to reduce the building's depth (illu. 107). To utilise the building's height effectively, it was decided to create two floors, providing space for family dwellings. The other buildings—the living wing, the garage, and the old grain storage barn—were easily divided into row houses. With the dimensions of these buildings now suited for residential use, the design process could move forward with the actual layout of the plans.

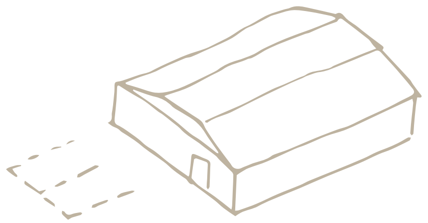


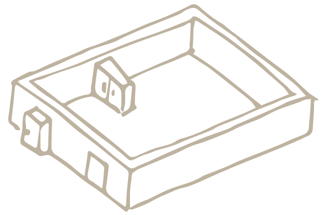
Ill.108: Building dimensions 1:500



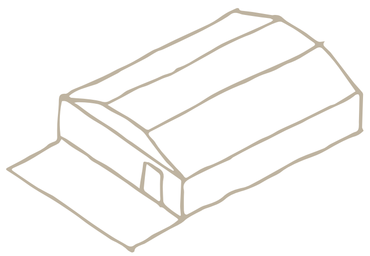


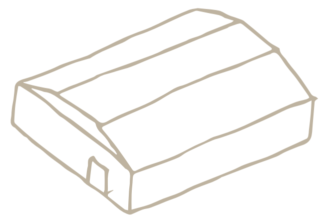
- Three room consists of 1 kitchen/living space and 2 separated bedrooms
- Total gross area pr housing unit 80-100 m²





- Parking ratio is 1,5 parking lot pr housing unit
- Storage is necessary both within the living space and outdoor





- Smaller private or semi-private outdoor areas with direct access from the dwelling
- Ideally one level plan

Ill.109: Three room dwelling

3-room dwelling

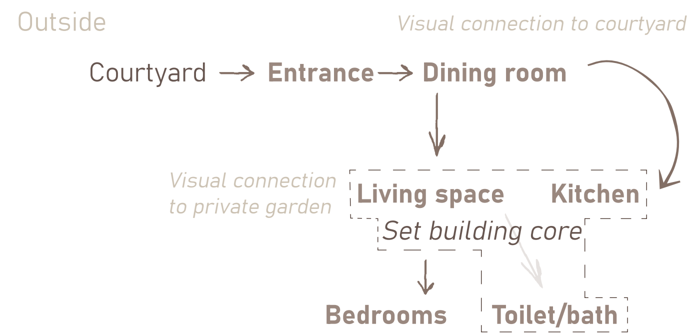
As the housing units were developed, general housing principles were established to ensure the layout met the needs of both the users and the housing association. Based on an interview with the head developer of the housing association, the principle of the 3-room dwelling was introduced. This section aimed to explore the principles behind the 3-room dwelling and identify the key elements that must be incorporated into the design of the housing units. These overarching principles have helped shape the building program, ensuring a functional dwelling for the users. To support this further, a study of plan drawings provided by the housing association was conducted. These drawings come from an actual housing project where the principles of the 3-room dwelling were applied (N+P Arkitektur, 2021).

Room principles

Building upon the principles of the three-room dwelling that informed the project's goal of creating quality architecture for housing associations, the next sections examined the housing principles from the user's perspective. This assisted in designing both the layout and interior of the housing units. The examination utilised the potential users presented earlier in the report (see page 56-57).

To design with the users in mind, everyday life situations were considered in this section to determine the possibilities for interior room layouts. On the following pages, each individual room of a housing unit were evaluated based on its functionality, comfort, and quality for the users. The rooms evaluated are presented in Illustration 110, where a sketched diagram illustrates the transitions between each space. It is important to note that the kitchen and toilet/bathroom are the fixed building elements of the housing units, meaning these are the primary elements of the dwellings that cannot be adapted. The remaining rooms, however, are flexible and can be altered to meet the users' needs over time.

Diagram

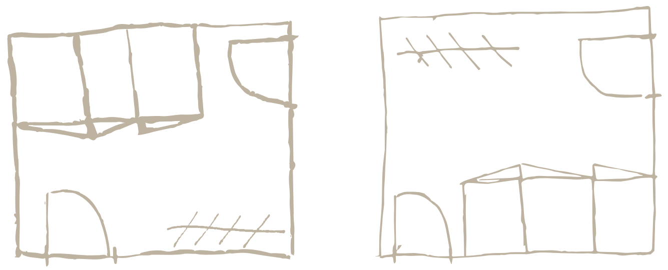


Ill.110: Room transistion

Entrance

Upon entering the housing unit, a practical space is necessary for storing outdoor wear and for placing shoes aside. For a family of four, this space must accommodate several coats, shoes, hats, and mittens, which should be easily accessible when leaving. Therefore, the entrance were designed as a separate room with multiple closets for storage, which can be closed off from the rest of the housing unit.

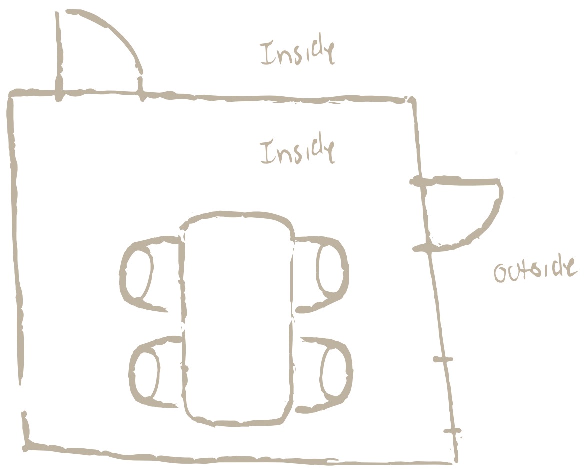
In addition to these practical considerations, it was also essential to ensure an appropriate and unhindered flow through the entrance. Therefore, the closets were relocated away from the entrance door to create a more open space for entry.



Ill.111: Sketch entrance

Dining room

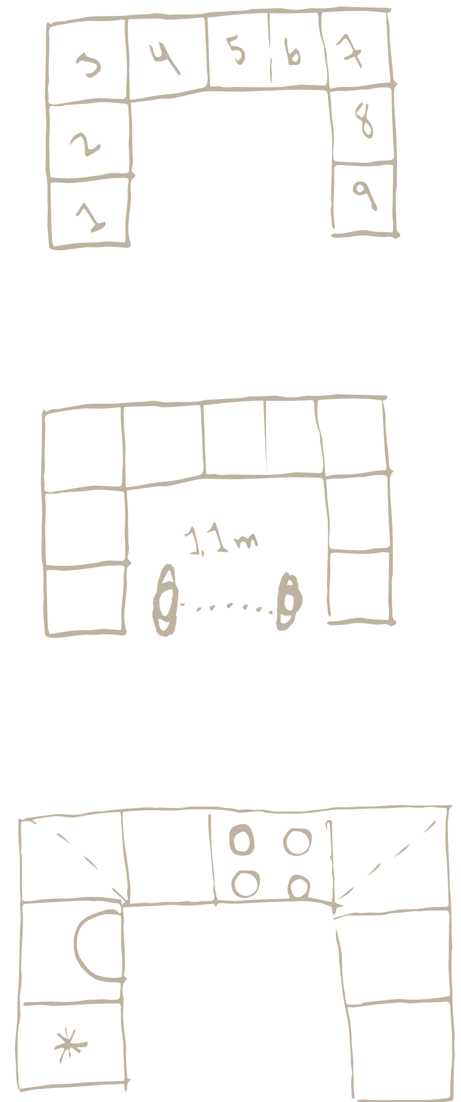
Moving beyond the entrance, the dining room appears, situated within an open-plan layout alongside the other social spaces. The dining room must accommodate seating for at least four chairs to serve the residents of the housing unit. Additionally, a visual connection to the courtyard was incorporated to strengthen social ties with neighbouring residents. This connection is further emphasised by a terrace door, which opens the space to the outdoors.



Ill.112: Sketch dining room

Kitchen

The kitchen is located in the same open space as the dining room. The kitchen had to be functional for an entire family, meaning that a sufficient amount of countertop space for kitchen work was integrated. With essential kitchen appliances, such as a fridge, stove, sink, and dishwasher, an evaluation of at least eight kitchen modules was necessary to optimise the layout.



Ill.113: Sketch kitchen

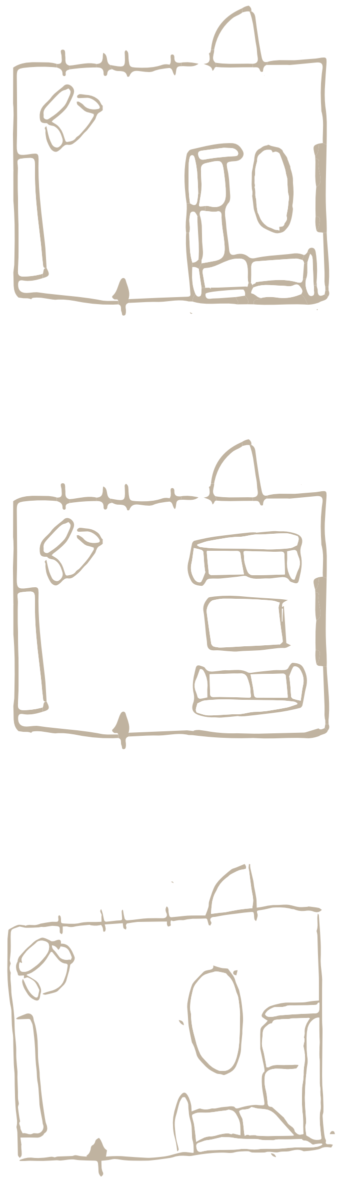
Living space

Different sizes of the living room spaces were investigated to determine the characteristics of each space in the various housing units. In the old cattle barn, the two-story dwelling, a living room space of 5x3,5 m was possible, while the living wing and garage could accommodate a living area of 4x2,5 m. This analysis informed the sketching phase, during which the initial sketches featured very narrow and elongated living spaces, which were not optimal for functionality or comfort.

Ill.114: Living spice dimensions

Different sizes of the living room spaces were investigated to determine the characteristics of each space in the various housing units. In the old cattle barn, the two-story dwelling, a living room space of 5x3,5 m was possible, while the living wing and garage could accommodate a living area of 4x2,5 m. This analysis informed the sketching phase, during which the initial sketches featured very narrow and elongated living spaces, which were not optimal for functionality or comfort.

The living space needed to be positioned on the opposite facade of the courtyard, where another terrace door leading to a private garden could be placed. This is shown in Illustration 115, along with other interior elements that must be incorporated into the plan layout.



Ill.115: Sketch interior living space

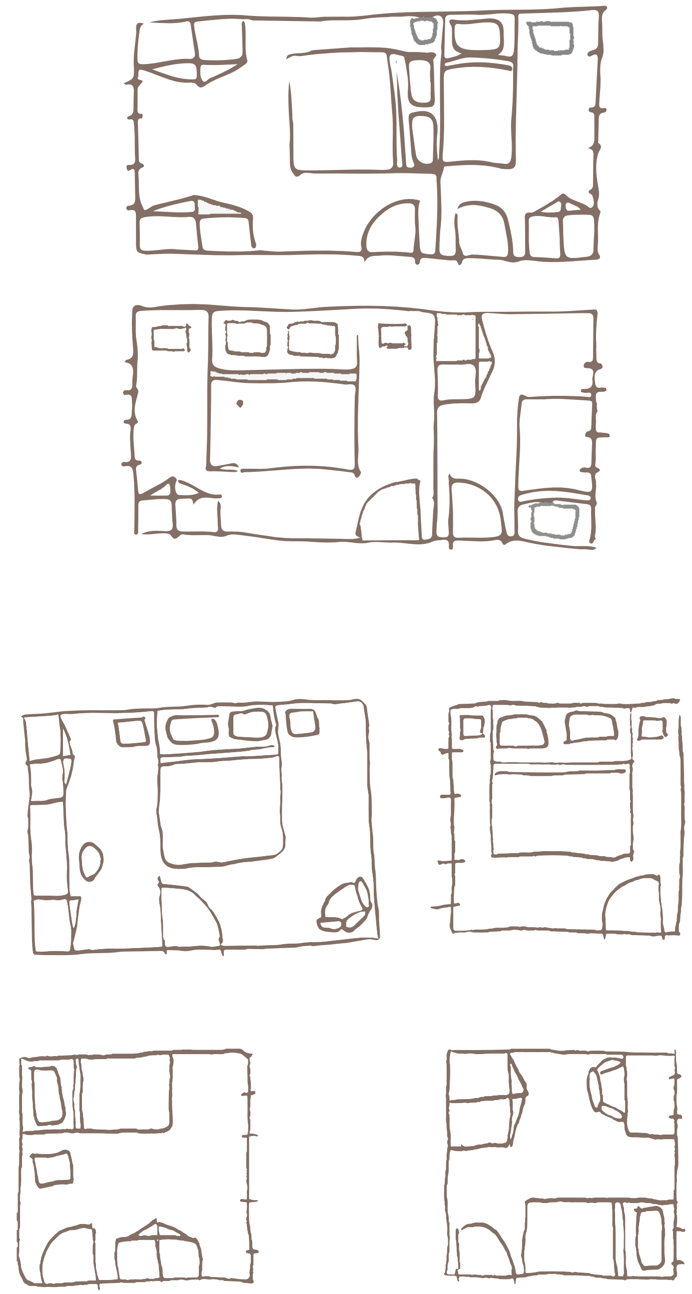
Bedroom

Given the variety of housing units and users, the bedrooms needed to accommodate a wide range of needs. It was not feasible to create a single set of bedrooms that could meet the demands of every user while still fitting within the existing buildings. As a result, the bedrooms were divided into two distinct scenarios: the main bedroom and the secondary bedroom.

The main bedroom, being the largest, needed to accommodate two adults, for example, a pair. It required a double bed, a minimum of three to four closets, and sufficient space for the two individuals to move comfortably. This was achieved by ensuring approximately one meter of space between the bed and the wall, allowing easy access for a person to enter the bed.

The secondary bedrooms could serve as either children's rooms or home offices, depending on the residents' needs. A children's room must include a single bed, one to two closets, and ideally a desk.

A key element that needed be integrated into all of the plans is windows, to ensure a comfortable space with adequate daylight and the possibility for natural ventilation.

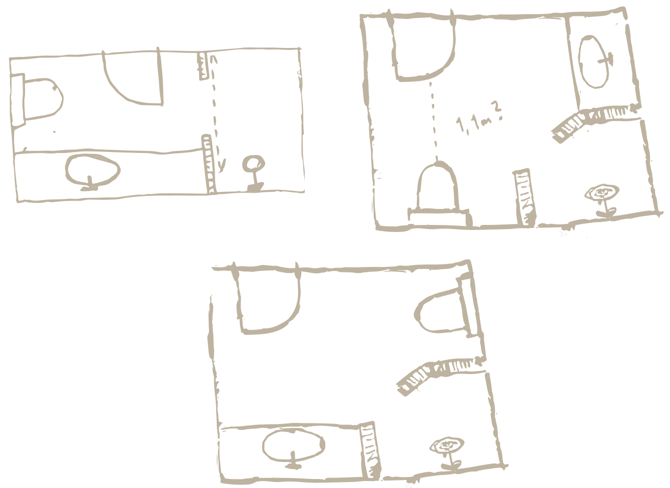


Ill.116: Sketch bedroom iterations

Toilet/bath

The size of the toilets and bathrooms within the housing units was limited, as the design prioritises the social rooms and bedrooms. Multiple iterations of the interior layout were developed to optimise the space without compromising comfort and quality.

Countertop space is essential for both storage and functionality; therefore, it has been assessed to ensure it is optimised to maximise storage as much as possible. In addition, several design iterations of the bathroom niche were conducted to examine a spacious layout that would be suitable for all users. Different niches were incorporated into the design of Landbo's housing units, as they were constrained by the dimensions of each individual room.



Ill.117: Sketch toilet/bath interior

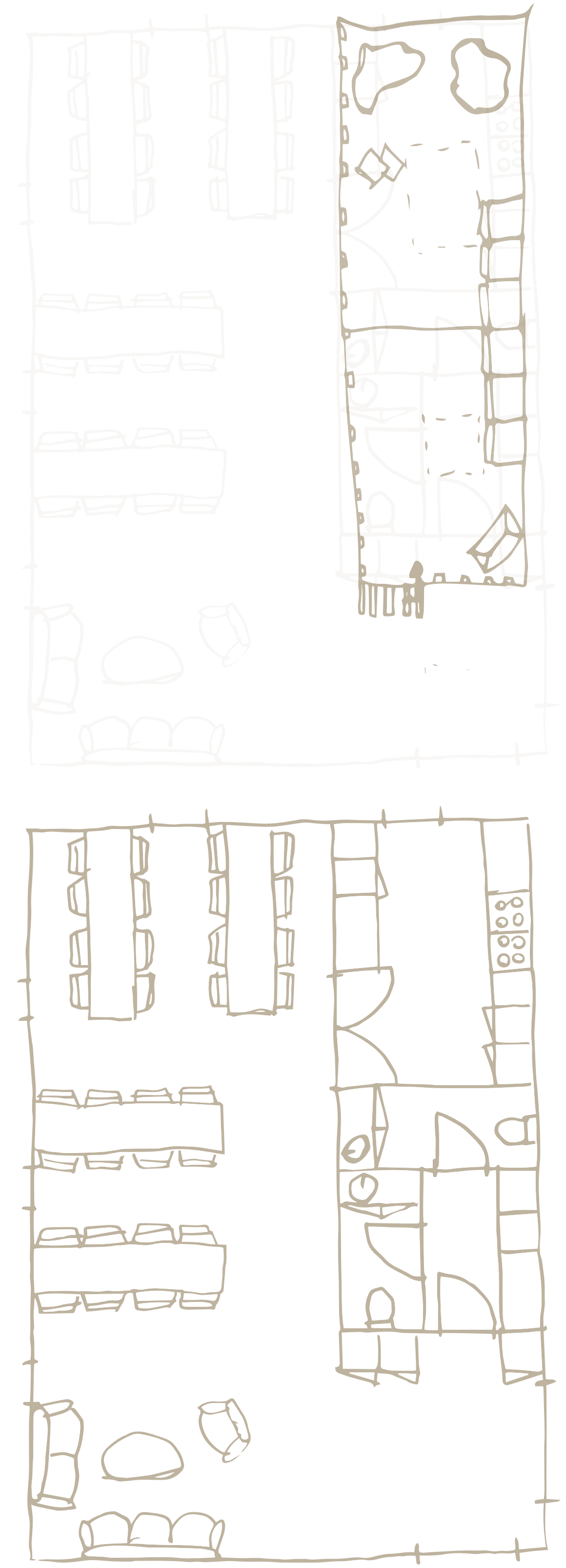
Apartments

To support the concept of housing rotation and adaptability, two rentable apartments were designed for external users or acquaintances of the residents to utilise. These apartments needed to provide space for a double bed and an additional single bed, at least two closets, and a toilet/bath. In the first iteration, a shared bathroom between the two apartments was created, but after further consideration, this was later revised to include individual bathrooms for each apartment.

Ill.118: Sketch apartments iterations

Common house

The common house was introduced somewhat later in the design of Landbo, therefore only a few iterations were made for this part. The common house needed to accommodate all the residents of the site at once for communal dinners and other social events. It was required to include a larger kitchen, as well as dining space for approximately 30 people. Storage for cutlery, plates, and other tableware had to be incorporated into the design, along with a seating area for more informal and relaxed gatherings. Toilets and a laundry room were placed adjacent to the kitchen space for technical installations. To ensure a reasonable ceiling height within these areas, a loft was created. The loft provides an additional space for residents, where children can retreat to play. It could also serve as a reading nook, playroom, or extra storage space, depending on the residents' needs.



Ill.119:Sketch common house interior

exterior & surroundings

The next section sought to investigate the exterior urban elements surrounding the site. This includes the connections to the city, the green structures, and the outdoor materials, all of which were examined to complete the transformation of the site.

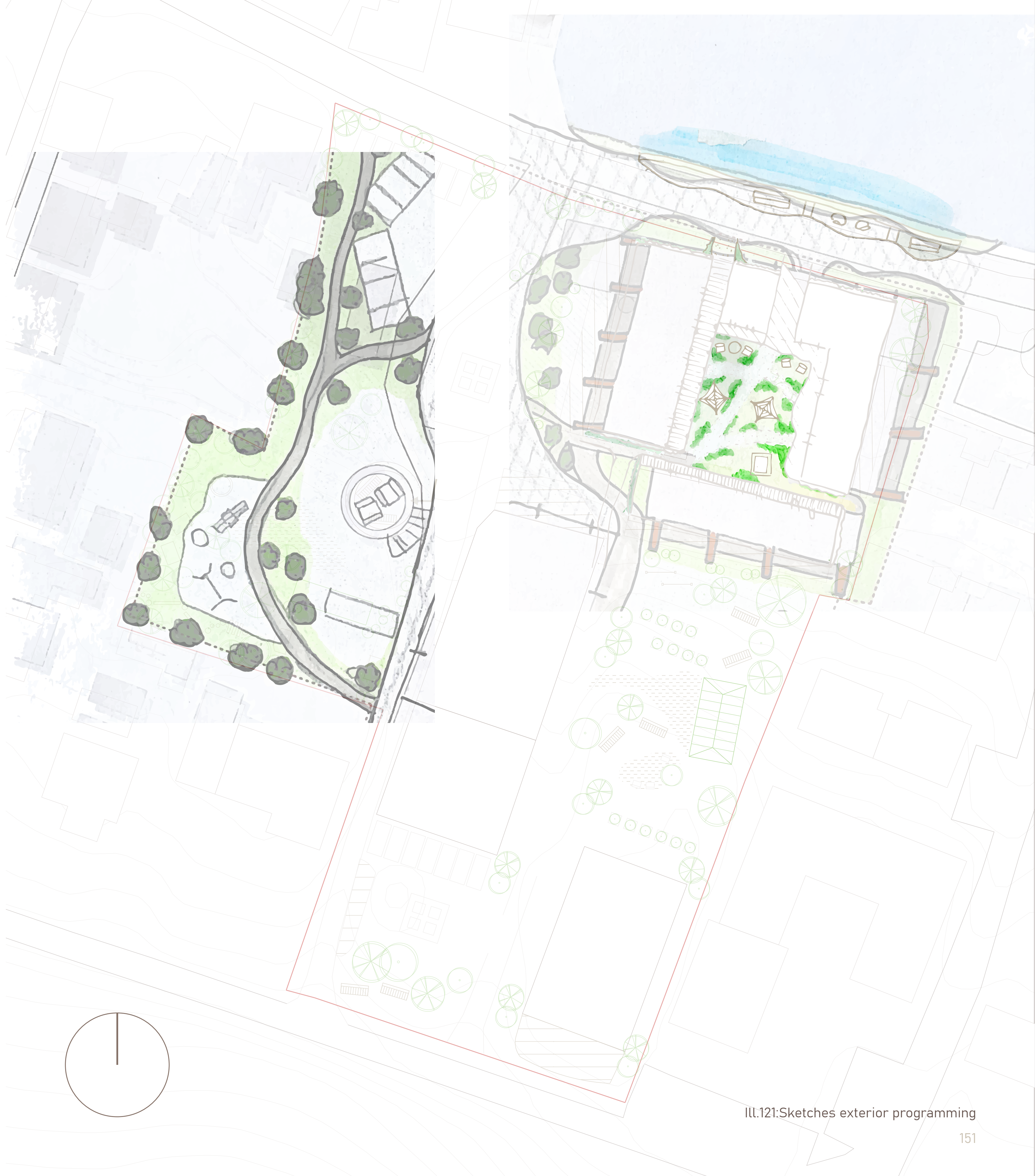
The first part will focus on the iterations of the outdoor spaces. Following this, the detailed design of the inner courtyard, which forms the area for social meetings between the dwellings, will be presented, whereas a mood board showcasing the greenery and materials used as inspiration for the exterior's atmosphere will be introduced.

Ill.120: Render entrance

Exterior programming

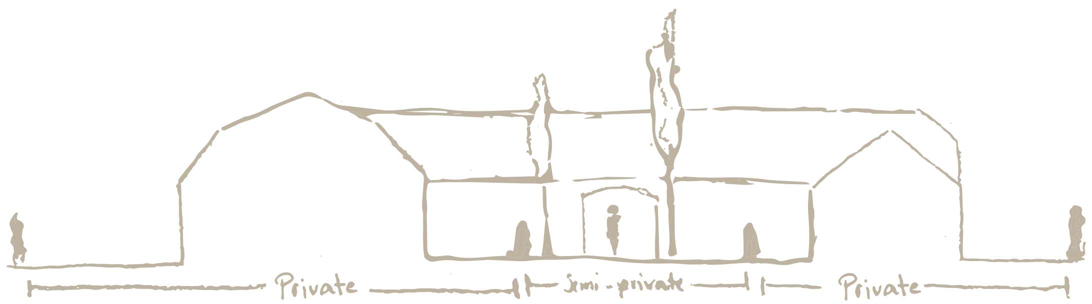
The exterior layout has undergone several iterations, with different subsections being the focus at various stages. Each time the building functions changed, the surrounding exterior was adjusted accordingly. The courtyard has been the primary focus in terms of detailed design, while the rest of the site has been designed mainly at a conceptual level.

To the south, a greenhouse was created, where raised beds were provided for growing flowers and vegetables. This space functions as an extension of the residents' gardens, which they can share with one another. Between the utility buildings and the farm wing, a green space for play and other activities, such as grilling and socialising, were established. To the west, a playground and park-like surroundings were created for the residents of both Landbo and Råby to enjoy for walks and relaxation.



Ill.121:Sketches exterior programming

Courtyard



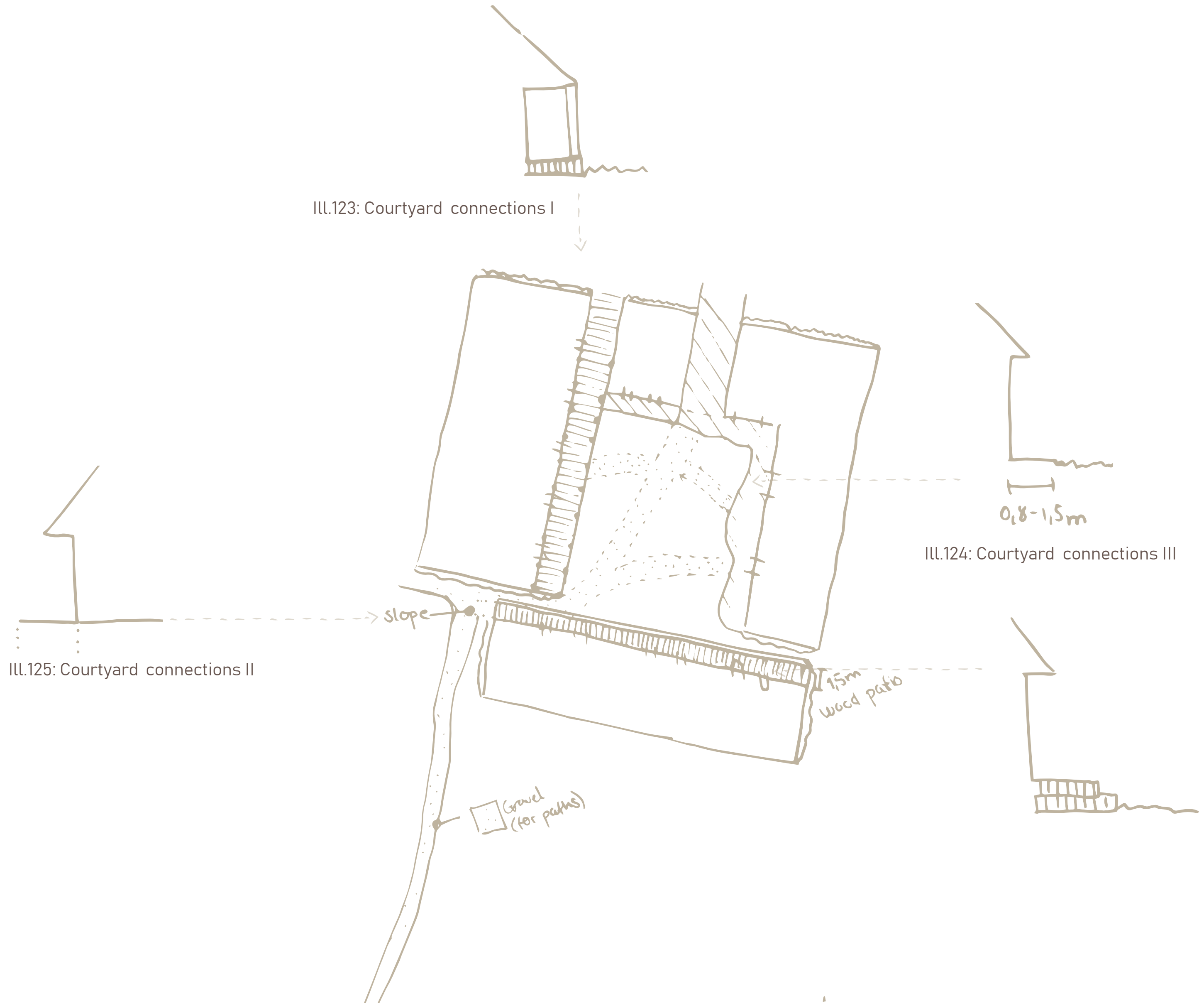
Ill.122: Courtyard zones

The inner courtyard between the housing units needed to be carefully detailed to support the community's relationship with one another. Despite the high number of outdoor spaces on the site, the courtyard offers distinct qualities.

From the edge zone of the housing units, a semi-private space opens up. Using principles of transition and connection, several initiatives were incorporated (Appendix 16: Connections). From the old cattle barn, an overhang divides the private space from the rest of the courtyard, alongside a wooden patio with a single step. This step creates a levelled patio that distinguishes it from the dwellings. (See ill. 123).

The other building to the south, the old living wing of the farm, has an additional step from the courtyard. This is due to the terrain difference of the site. To the west of the patio, a slope is incorporated, extending from the path to the patio, allowing people with limited mobility, such as the elderly, to use it. (Ill.125).

In the old garage and grain store, the entrance to the buildings is level with the courtyard but is separated by a change in the pavement material. (Ill. 124).



Ill.123: Courtyard connections I

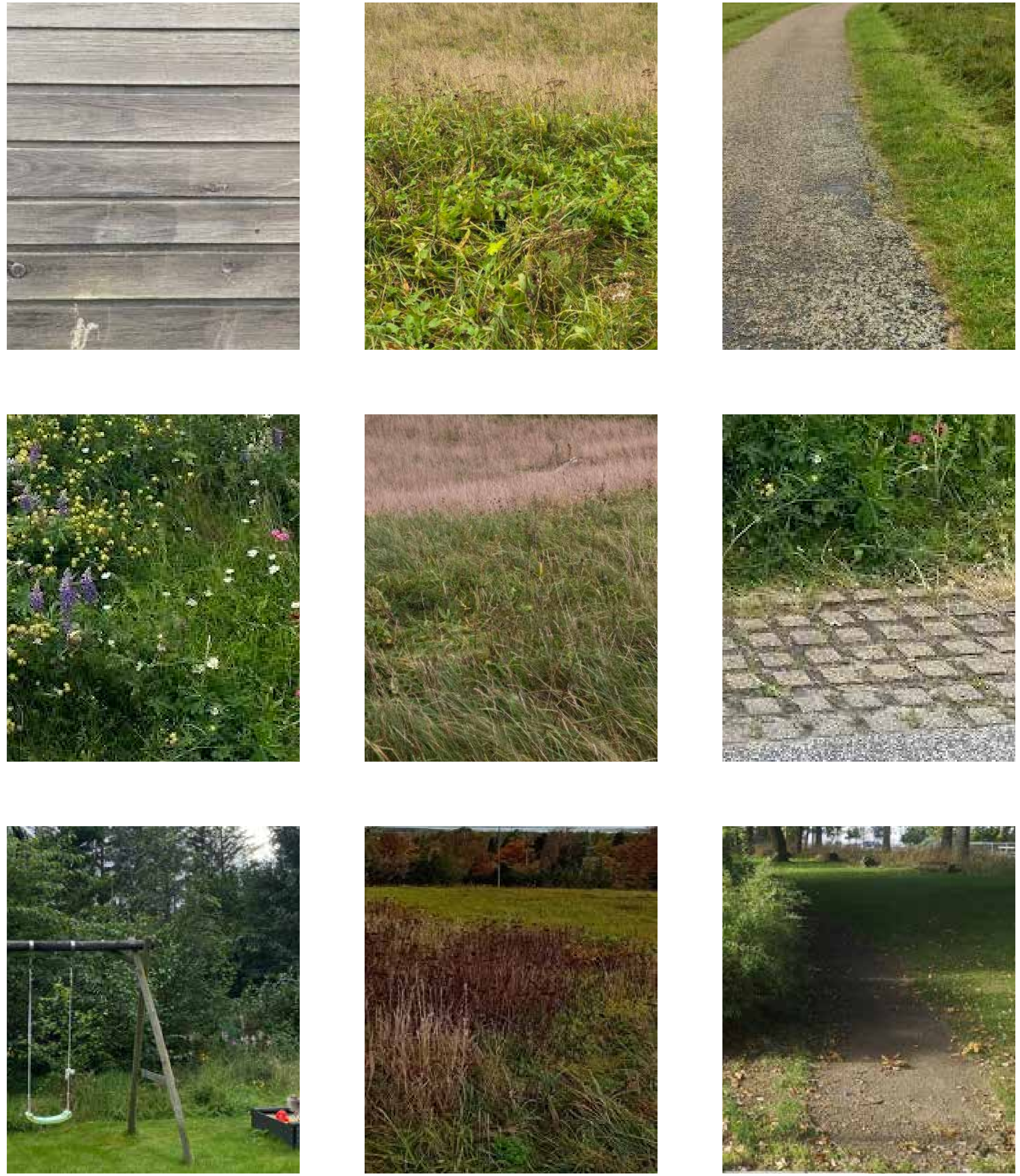
Ill.124: Courtyard connections III

Ill.125: Courtyard connections II

Greenery & pavement

Surrounding the site, additional greenery were incorporated to create distinct zones. Generally, more wild grass is desired, as it can enhance a natural atmosphere and, with its height, help divide different areas. In other spaces, common grass areas were sufficient, providing room for activities such as ball games or outdoor gatherings.

The road between the site and the village pond were changed to consist of armoured grass, which slows the speed of vehicles while still supporting the overall green structure. The armoured grass were extended through the entrance port and further into the beginning of the inner courtyard to create an inviting connection. The paths within the courtyard and in the park area to the west were made of gravel. For the road running through the site and the path leading from the courtyard to the greenhouse, the pavement should be hard, providing a comfortable surface for both cyclists and pedestrians.



Ill.126:Greenery board

facades & openings

This chapter presents different investigations and solutions for the façade expressions and placement of openings. First, a series of transformation principles will be presented and examined to define the optimal approach for the project. Following this, investigations into opening dimensions and façade expressions will be presented for the housing units and the common room, which undergoes a significant transformation. These investigations took into account cultural heritage, energy consumption, and the potential for global warming.

Ill.127: Render window

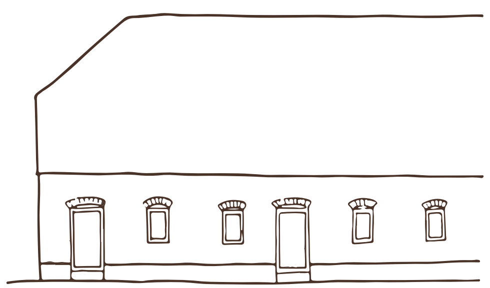
Transformation principles

To define the desired façade expression and window openings, various transformation principles were examined.

The façade principles (ill. 129) explore whether the transformation should focus solely on preserving the façades in their current state, thereby making a direct reference to the cultural heritage, or whether the transformation should be embraced through the introduction of either traditional or modern elements. As the existing farm buildings were currently uninhabitable, it was unrealistic to implement dwellings while preserving the façades in their original condition. Instead, it was more appropriate to embrace the transformation by incorporating new openings, while still including traditional features and detailing to honour the site's cultural heritage.

The opening principles (ill. 130) explored which intervention in the façade openings was most appropriate for the project. The primary criteria were to enhance the buildings' overall energy performance and support natural ventilation, while also implementing openings that were suitable for the users and the intended functions of the various buildings. Throughout the design process, a Be18 energy assessment was conducted to evaluate energy demand throughout the sketching.

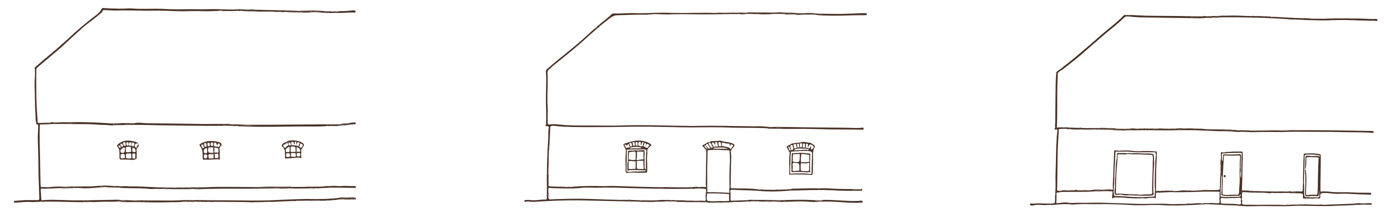
Result



Ill.128: Facade dwelling solution

As a result of the investigations, the transformation of the façade focused on creating new openings that corresponded to the updated functions, that improved the building's energy performance. The new openings embraced the transformation through the use of modern windows, while respected the cultural heritage by integrating brick cornice detailing.

Facade principles



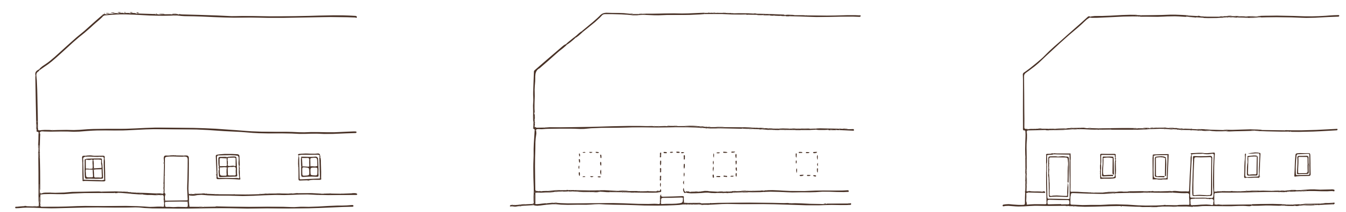
Ill.129: Facade principles

Preserve original facade
Embraces cultural heritage
Lack of adaption to new functions
No embrace of transformation

New traditional openings
Relates to cultural heritage
Adaption to new functions
Embraces the transformation

New modern openings
Relates little to cultural heritage
Adaption to new functions
Embraces the transformation

Opening principles



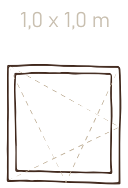
Ill.130: Opening principles

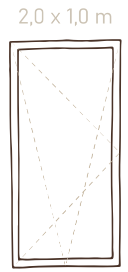
Keeping the original openings
Low glopal warming potential
High energy demand
Irregular placement
Not optimal for user or functions

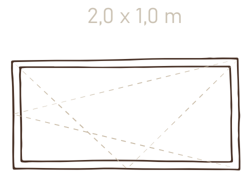
Utilising existing openings
Medium glopal warming potential
Low energy demand
Irregular placement
Not optimal for user or functions

Making new openings
High glopal warming potential
Low energy demand
Utilise passive strategies
Optimal for user or functions

Windows shapes

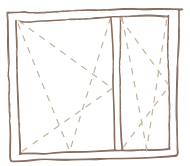




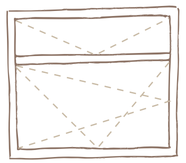


Ill.133: Window shapes

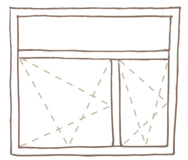
Windows openings



Vertical division
Large openings
Easy to open



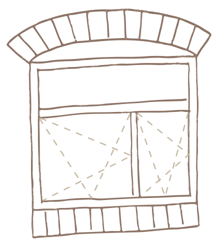
Horisontal division
Large openings
Easy to open



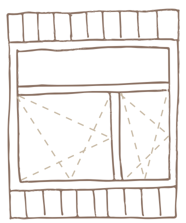
Combined division
Smaller openings
Easy to open

Ill.131: Window iterations

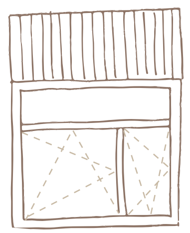
Cornice details



Curved cornice
Respects preservation
Contrast to modern window



Streight cornice
Respects preservation
Respects modern window



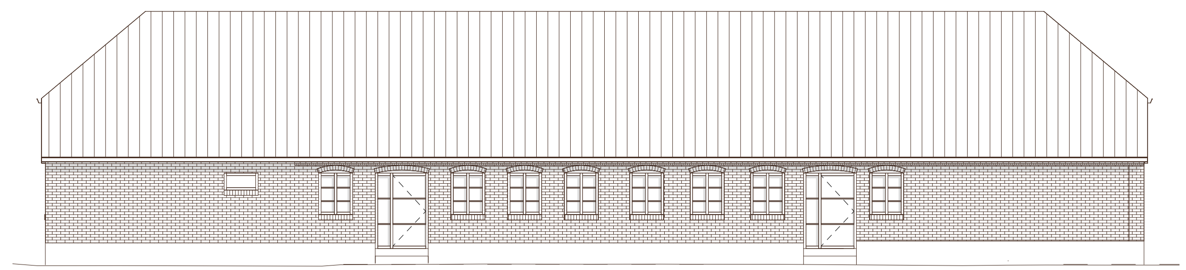
New material
Constrast preservation
Respects modern window

Ill.132: Cornice iterations

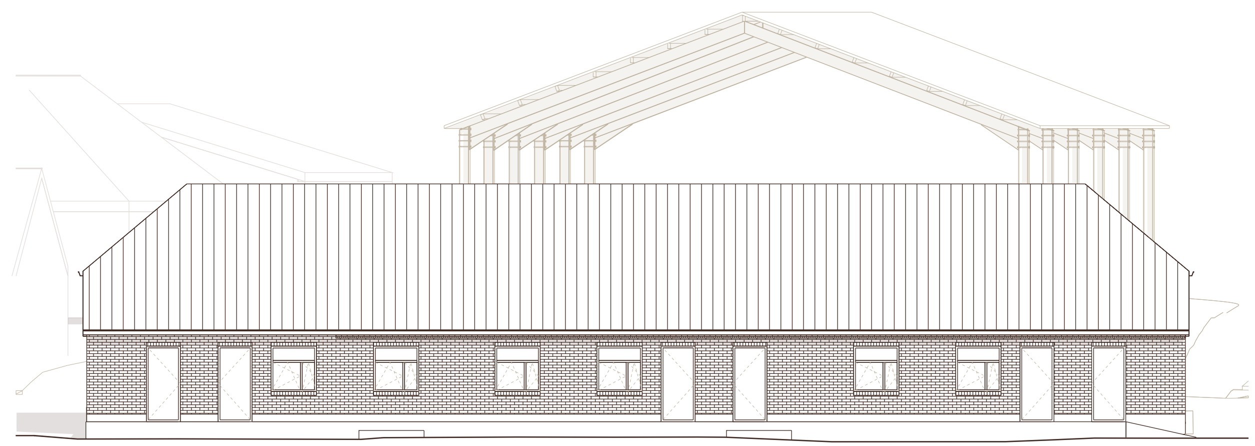
Openings in dwelling

When examining the façade openings in the dwelling units, an investigation into various window shapes was carried out. The square window was selected as the primary opening for the dwellings, while the vertical opening was chosen for doorways, facilitating direct interaction with the external environment.

As natural ventilation was a key factor in the design of the dwelling units, it was decided to subdivide the glazed area of the square window to support effective single-sided ventilation. The combined division was selected as it was easy to operate and allowed for smaller ventilation openings during the winter months. Since the original buildings featured curved cornice detailing, a new cornice design was developed for the new windows. A straight cornice was chosen, which complemented the modern design of the windows and façade.



Ill.134:Elevation: original openings 1:200



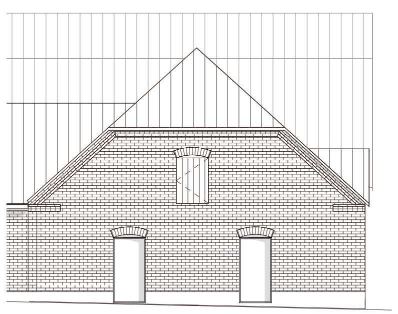
Ill.135:Elevation: new openings1:200

Openings in common house

When it comes to the openings in the common room, it was important that they not only suited the internal functions but also responded to the building's external orientation. The north façade of the common room is the outward-facing facade, overlooking the village pond and the rest of the town. Here, the traditional aesthetic of the façade played a significant role in shaping the identity of the farm and its cultural heritage as perceived from the outside. For this reason, it was decided to preserve the northern façade of the farm as much as possible, while still addressing the comfort needs of its users. However, the façade currently featured only small, outdated windows, which did not allow sufficient natural daylight to enter the common room.

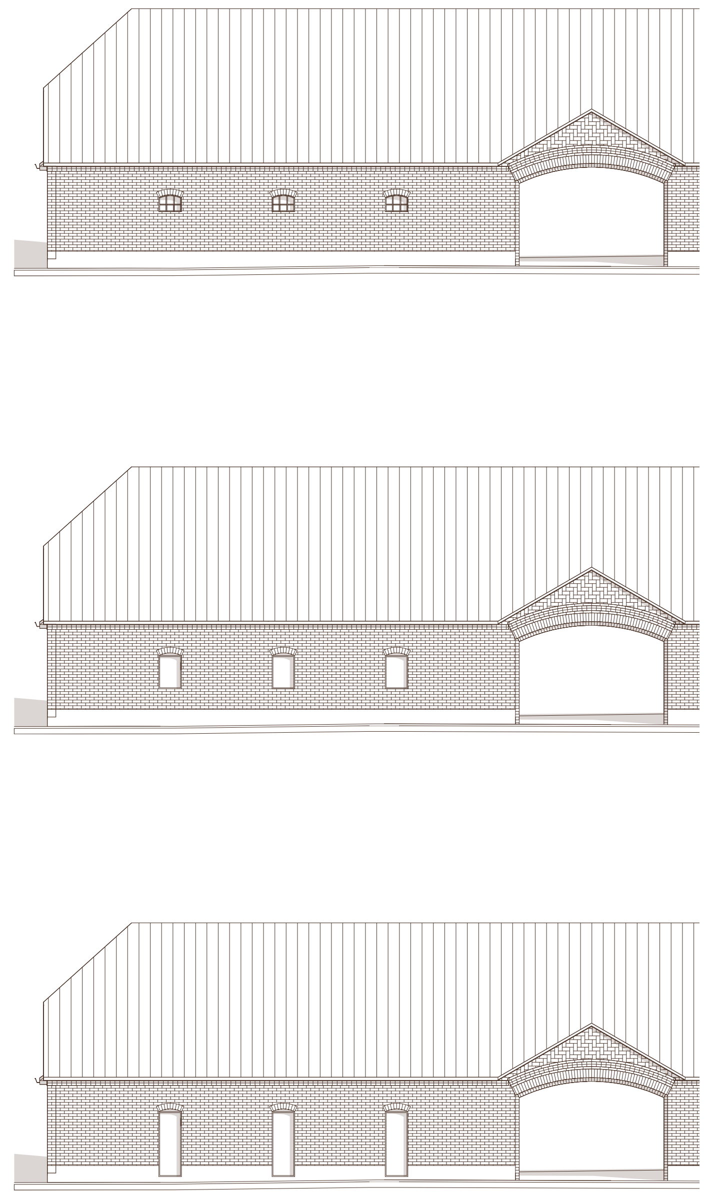
Instead, an investigation was carried out into extending the existing openings while maintaining the same number and width as the original windows. This approach aimed to improve the windows' performance while respecting the cultural heritage of the façade, as no additional openings were introduced on this elevation.

Result



Ill.136:East elevation: Openings examination 1:200

The medium extension option was considered to provide insufficient glazed area for adequate natural daylight. It was decided to implement large, extended openings in the façade to ensure an optimal common room for the residents to use, without the space feeling enclosed or lacking in natural daylight. On the east façade of the common room, it was also decided to extend the width of the openings to accommodate doors in both the kitchen and the communal space. This allowed for more effective natural ventilation and provided additional escape route in case of fire. To further improve the natural light within the common house, two additional roof windows were added, oriented towards the south.



Keeping the original openings

Embraces the cultural heritage

Low natural dayligt and passtive stragies

Low glopal warming potential

High energy demand

Medium extended openings

Respects the cultural heritage

Medium natural dayligt and passtive stragies

Medium glopal warming potential

Low energy demand

Large extended openings

Respects the cultural heritage

High natural dayligt and passtive stragies

Large glopal warming potential

Medium energy demand

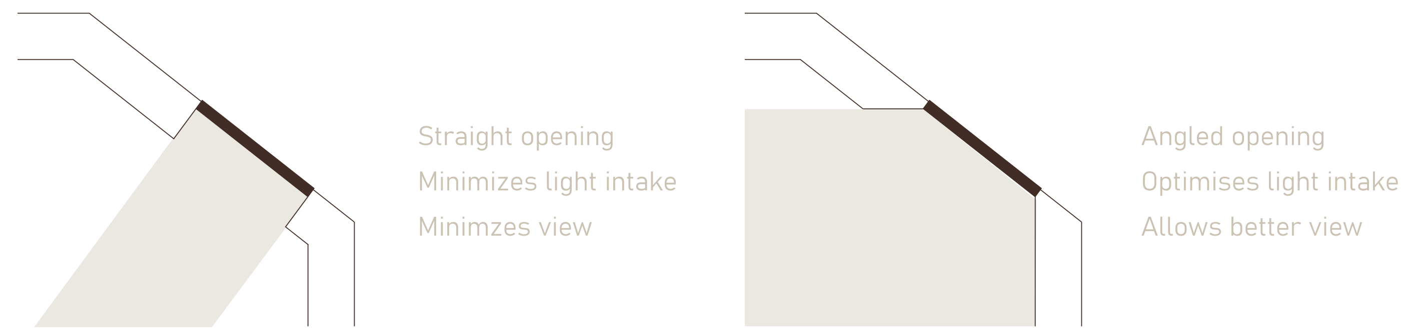
Ill.137:North elevation: Openings examination 1:200

Roof openings principles

To ensure sufficient natural daylight in the various buildings and rooms, additional roof openings have been implemented in several structures. To determine the most effective solutions, different principles have been examined. In the building with two levels, the upper level is situated directly beneath the roof, permitting only sloped roof openings. Here, the principle of angled openings was selected to allow more natural sunlight into the rooms and to provide improved views for the residents. For this type of opening, an integrated notch was implemented, creating a small seating area beneath the windows — ideal for decoration or placing a cup of coffee, for example. This approach also allowed the building envelope's insulation to be incorporated within the notch. As these windows will also function as emergency escape routes, their height and dimensions were defined in Appendix 17: Fire considerations.

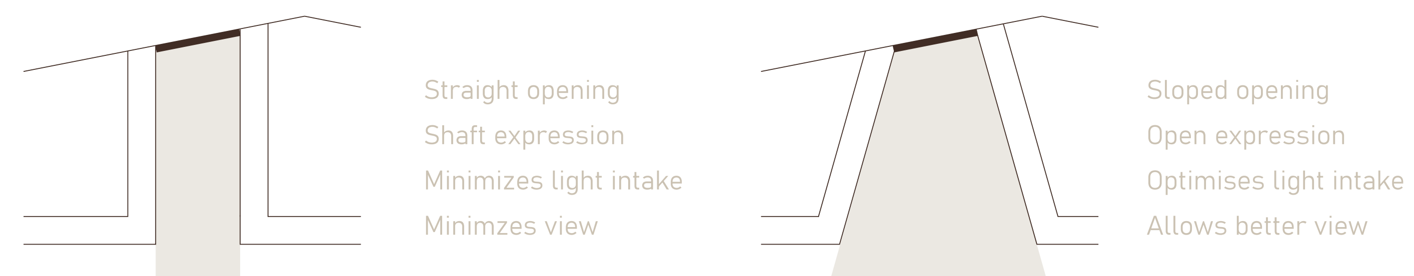
The principle of sloped roof openings at the top of the roof, as well as on gable roofs with unused attics, has been examined for its potential to introduce various forms of light shafts. In this context, sloped openings have been selected to ensure greater natural daylight intake and to create a more open and bright interior expression. This principle will be implemented in the two-level housing units and the flexible dwelling units, due to their limited façade area available for natural light.

Side roof opening principles



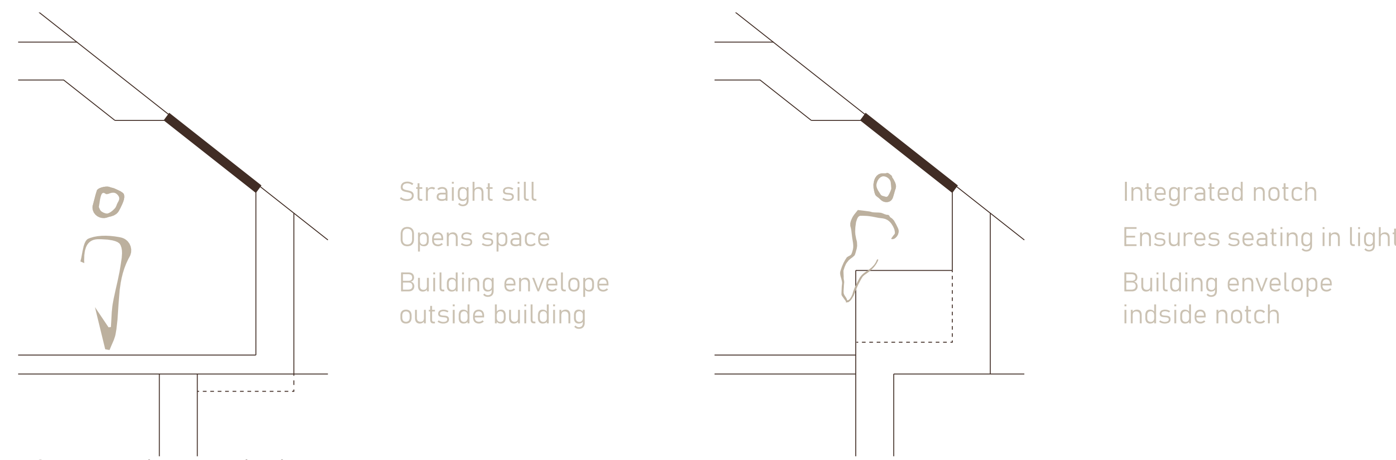
Ill.138: Roof openings examination

Top roof opening principles



Ill.139: Roof openings examination

Window sill principles



Ill.140:Roof openings examination

materials and aestethics

The final chapter of the design process focused on the topic of materials and aesthetics. This section will present various investigations that defined the use and reuse of materials in specific contexts. Initially, the chapter will showcase preliminary sketches and ideas for material combinations and aesthetic experiences in different scenarios, where a series of transformation principles will be presented. Following this, material examinations of interior surfaces in both the dwelling units and the common room was outlined to specify which materials are used in each space. An overview of the different building components added during the transformation to make the buildings habitable will then be provided, based on various investigations. All investigations in this chapter will also consider cultural heritage and global warming potential.

Ill.141: Render patio

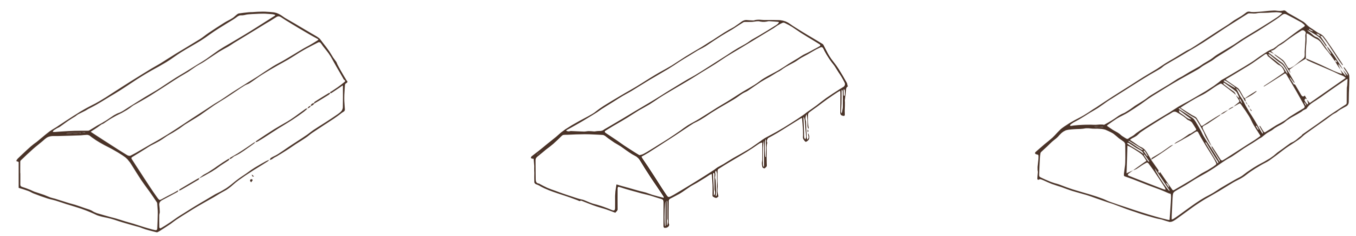
Transformation principles

To begin specifying the transformation of the different buildings, with materials and aesthetics in mind, various principles were investigated. The volume study (ill. 142) focused on the transformation of the building volumes.

The old cattle barn included in the wing-farm, as described in the programming section, was transformed into two-storey dwelling units. Currently, the building did not provide enough natural daylight to each dwelling due to its large depth. Therefore, it was decided to remove a section on the first level and create a small semi-public space outside the entrance.

The materials study (ill. 143) investigated how the transformations should consider materials. The main focus was to preserve as much of the existing material as possible, as this will ensure the lowest global warming potential. However, for buildings where this was not optimal, materials should be chosen with consideration for life cycle assessment. Therefore, primarily organic or reused materials have been implemented.

Volume principles



Ill.142: Volume principles

Preserve volume

Embraces the cultural heritage

Low global warming potential

Remove section at first level

Respects the cultural heritage

Creates semi-public space outside

Medium global warming potential

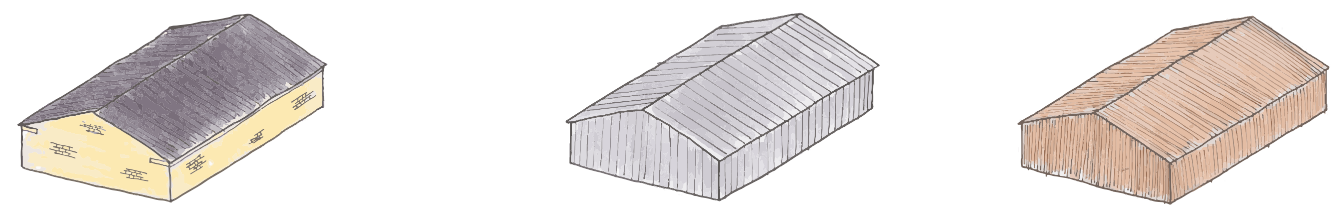
Remove sections at second level

Respects the cultural heritage

Creates thermal bridges

High global warming potential

Materials



Ill.143: Material considerations

Preserve material

Embraces the cultural heritage

Low global warming potential

Transform with industrial material

Respects the cultural heritage

High global warming potential

Transform with organic material

Gives new identity

Low global warming potential

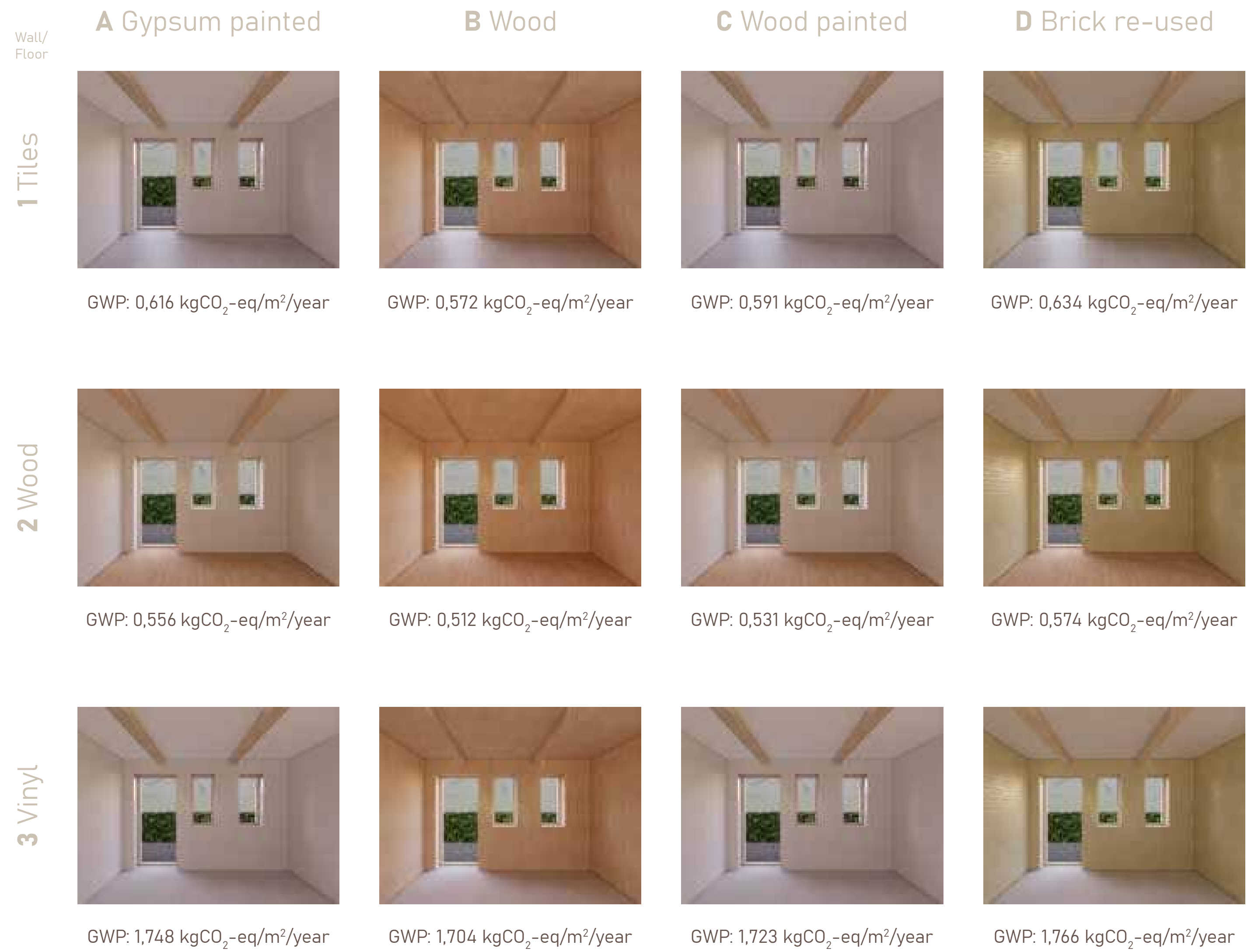
Dwelling material

The next two sections investigated the interior materials for the dwellings and the common room. In this investigation, the tool LCAbyg was used to calculate the materials' embedded global warming potential, utilising generic data. To evaluate the materials on the interior surfaces in the dwellings, a matrix of various wall and floor materials were developed (ill. 144). In addition to aesthetic and spatial experience, the matrix also took the global warming potential of the different material combinations into consideration.

As it can be seen in the scheme, the different rooms in the housing units were listed with a description of the important criteria the materials must fulfil. In the matrix, rooms with white walls and ceilings open up and lighten the spatial experience. White-painted wood performs better than gypsum in terms of GWP, so column C is chosen as the wall and ceiling material. The entrance and toilet required durable and practical materials; therefore, tiles were chosen as the flooring material in these rooms due to their lower GWP than vinyl. The living room and bedrooms required a calm and soft material, which wood flooring contribute to. Since the kitchen is directly connected to the living room and requires a functional and light material, wood flooring was also chosen here.

Result

Entrance	Practical to clean, functional, light and durable materials	**C1**
Kitchen	Functional, light materials	**C2**
Bathroom	Practical to clean, light and durable materials	**C1**
Living room	Comfortable, warm experience, light and soft materials	**C2**
Bedroom	Comfortable, warm experience, calm, light and soft materials	**C2**



Ill.144: Material matrix

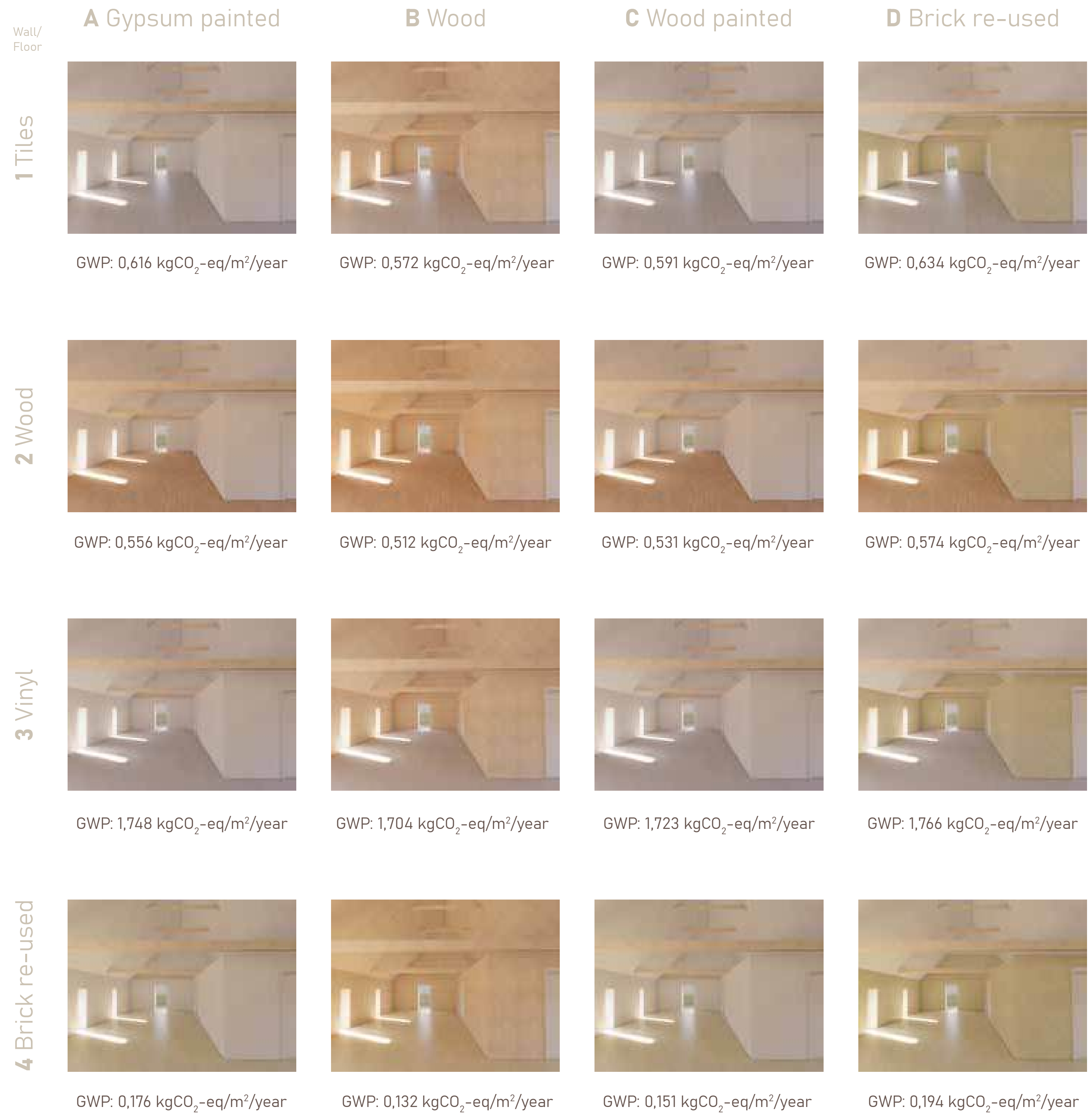
Common room material

To investigate the materials for interior surface within the common room a material matrix (ill. 145) was again developed taking global warming potential into consideration for the different combinations. Additional this matrix also considered brick flooring with bricks re-used from the demolished parts of brick facades on site. In the scheme below the rooms included in the common room were listed with different requirements to materials.

As it can be seen in the matrix the material combination with white painted walls again helps opening up and lighten the spatial experience of the room, together with enhancing the preserved beams from the original building. Again, here the white painted wood was chosen as the wall and ceiling material due to its low GWP. In the matrix it can be seen that re-used bricks as flooring had a very low GWP. By implementing re-used bricks in the flooring of the common room and laundry room speaked to the story telling of transforming the old farm and respecting the old materials by including them in a new way.

Result

Common room	Functional, comfortable, light and durable materials	**C4**
Industrial kitchen	Practical to clean, functional, light and durable materials	**C1**
Toilets	Practical to clean, light and durable materials	**C1**
Laundry room	Functional, light and durable materials	**C4**



Ill.145: Material matrix

Spatial experience

The spatial experience (ill. 146) illustrated how the interiors of the different buildings should be transformed according to ceiling design. As shown in the illustration, the horizontal ceiling was optimal for the housing units due to its simplified room experience. It also ensured there is no need to adjust the roof construction or roof material. The sloped roof with the horizontal ceiling over the smaller rooms was ideal for the common room, as it provides a more open spatial experience and references the original building's vaulted ceiling. The horizontal ceiling, in this case, prevents a shaft feeling in the kitchen and laundry room, while also allowed for additional storage space. This solution resulted in a higher global warming potential, as larger interior surfaces need to be created and the construction must be reinforced to support the new insulated roof. However, since this solution provides a more open experience and enhances the overall quality, it were implemented in Landbo.

Spatial experience

Ill.146: Render spatial experience

Sloped ceiling + horizontal ceiling
Opens up space
Allows more storage space
High global warming potential

Sloped ceiling
Opens up space
Shaft experience in rooms
High global warming potential

Horizontal ceiling
Simplifies room experience
Optimal for dwelling units
Low global warming potential

Building envelope

Since most of the buildings were originally old barns with no insulation materials, it was necessary to create a new building envelope through re-insulation. As the SAVE analysis stated that the buildings within the wing-farm were worth preserving, it was decided to carry out internal re-insulation of the buildings.

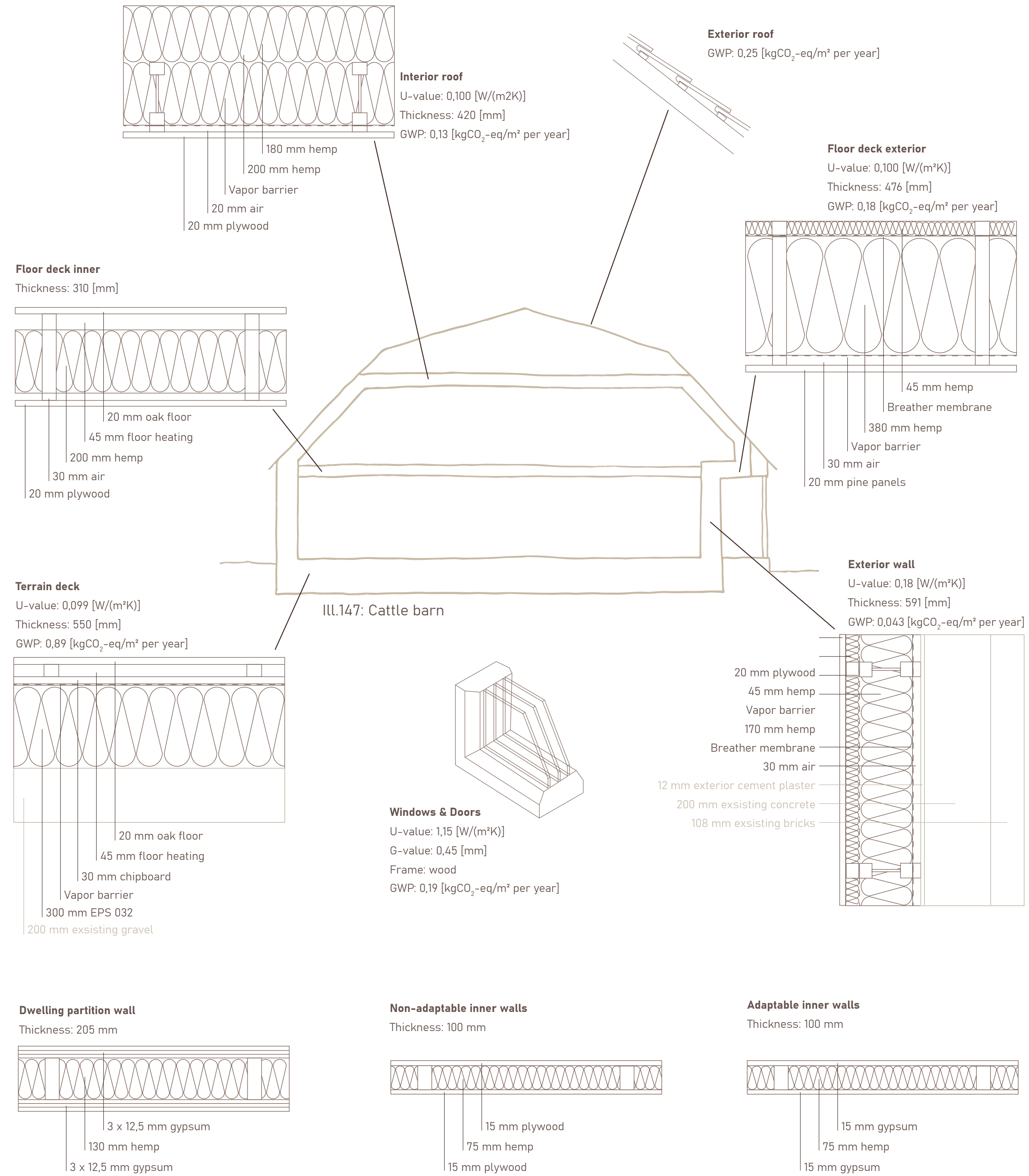
It was decided to investigate the large two-storey cattle barn (see ill. 147). Firstly, an investigation of insulation materials was conducted based on global warming potential and wall thickness, using the tool LCAbyg, which utilises generic data from the programme, along with EPD data (Appendix 18: Re-insulation). This resulted in hemp being the most optimal material due to its lower GWP and narrower thickness compared to mineral wool. Hemp was implemented in the construction of the roof, floor deck, exterior walls, and internal walls. The terrain deck, originally a concrete construction without insulation, was replaced with a new lightweight terrain deck construction made from stressed EPS and wood chipboards, to ensure reduced heat loss and lower GWP. Due to the implementation of windows in the roof of this building, a new roof construction was also incorporated into the transformation.

For the interior partition walls between the dwellings, an investigation into fireproof walls was conducted (Appendix 17: Fire consideration), again using LCAbyg. This resulted in a construction with narrow thickness and low material use. Two different interior wall constructions were then developed. The wood-based walls were used as stationary interior partitions for non-adaptable rooms, such as the toilet and kitchen, whereas gypsum-based walls were used for the adaptable bedrooms, as gypsum is a more cost-effective material than wood.

A life cycle analysis (LCA) was carried out using LCAbyg to investigate the embedded global warming potential of the building envelope's renovation (see building envelope parts in ill. 139). The investigation utilises both generic data from LCAbyg and EPDs (Appendix 19: LCA Landbo). The results of the optimisation was used in a further discussion on building rotation (p. 180), placing Landbo into a new moving scenario principle in Råby and comparing it to the conventional moving principle.

Properties amount

Building part	Area
Exterior roof	494 m^2
Interior roof	522,1 m^2
Floor deck exterior	40,9 m^2
Exterior walls	220,4 m^2
Ground floor deck	366,0 m^2
Doors and windows	80,4 m^2
Solar panels	50 m^2



Ill.147: Cattle barn

Ill.148: Drawing green house

epilogue

Finally, the next section will summarise the project and process in a discussion of the housing rotation principle, followed by a conclusion that wraps up the thesis. At the end, a reflection will evaluate the thesis' outcome and process, after which a brief perspective section will discuss the learnings and the overall potential of this thesis.

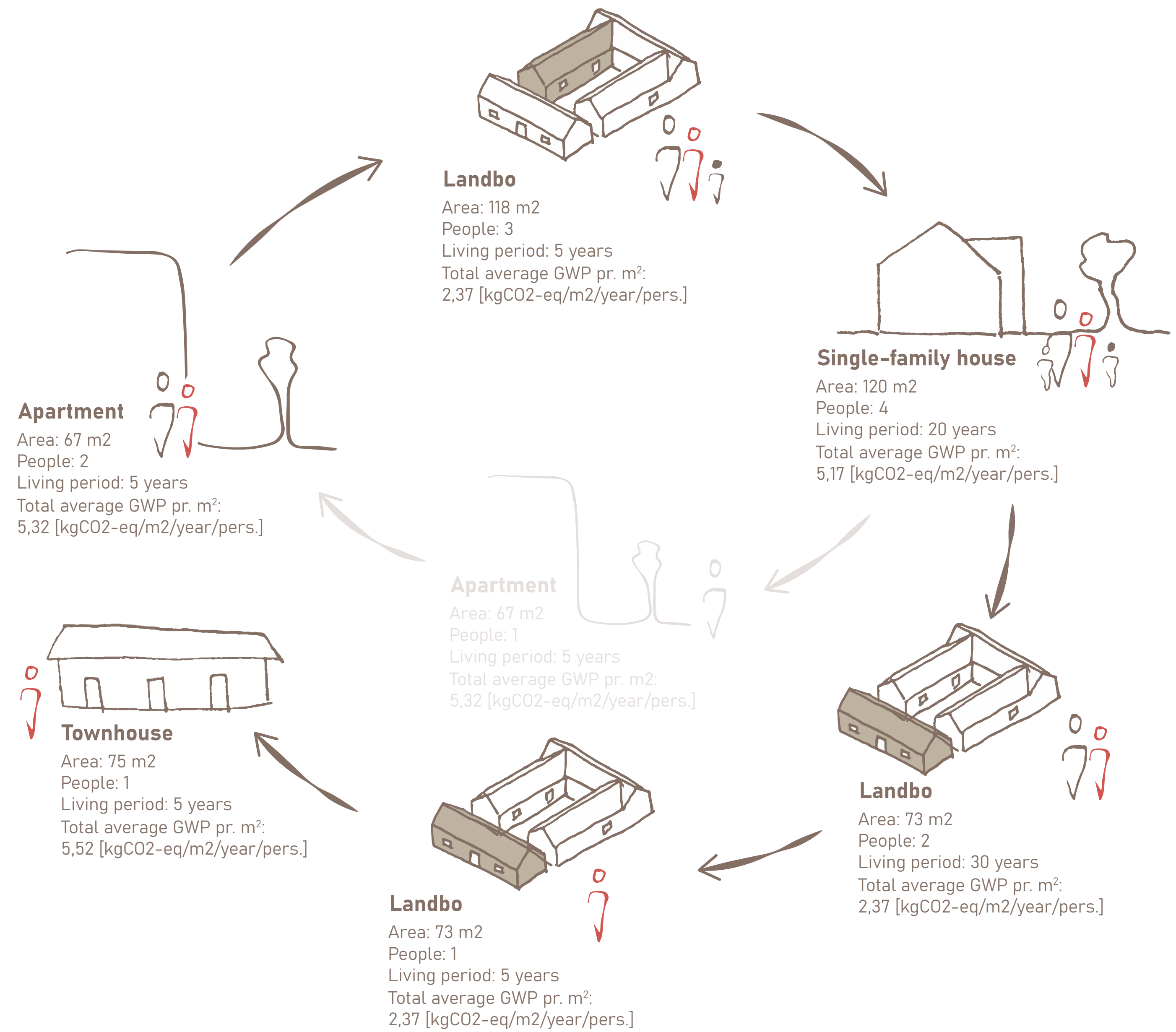
discussion

The principle of housing rotation has, throughout this thesis, been investigated and applied to the city of Råby and the project solution Landbo, with the aim of developing the conventional dwelling pattern seen today and reducing its climate footprint. This section aims to discuss the method and the results of implementing the housing rotation principle within this thesis.

The investigation (p. 58-75) presented an examination of implementing housing rotation in Råby, based on generalised case studies of different typologies. Here, the moving scenario of an individual was presented in both a conventional moving principle and a housing rotation principle. From this, a comparison of the two moving principles concluded that housing rotation ensures a lower climate footprint by developing the villages and renovating the existing buildings. Since the purpose of this investigation was to gain an understanding of the influence of housing rotation, the results are based on assumptions of typical moving patterns and fictitious typologies. To gain more realistic results, a detailed investigation of specific housing units and a mapping of people's moving patterns in a specific city would provide a more accurate outcome, but this was not achievable within the framework of this thesis.

From the previous investigations into housing rotation, the knowledge and insights gained are incorporated into this section for comparison. Landbo is a housing association to be integrated into the housing rotation of Råby, ensuring more diverse dwelling opportunities within the village (see ill. 149). By implementing row-house dwellings with units of varying sizes, residents are able to move between homes that suit their changing life situations, both within Råby and within Landbo itself. The row-house typology optimises the use of square metres by accommodating more people.

Living period	**Total average global warming potential**	
[year]	[kgCO_2-eq/m^2/year]	[kgCO_2-eq/m^2]
5	5,32	26,6
5	2,37	11,9
20	5,17	103,4
30	2,37	71,1
5	2,37	11,9
5	5,52	27,6
	Sum:	252,5
	Average pr. year:	**3,6**

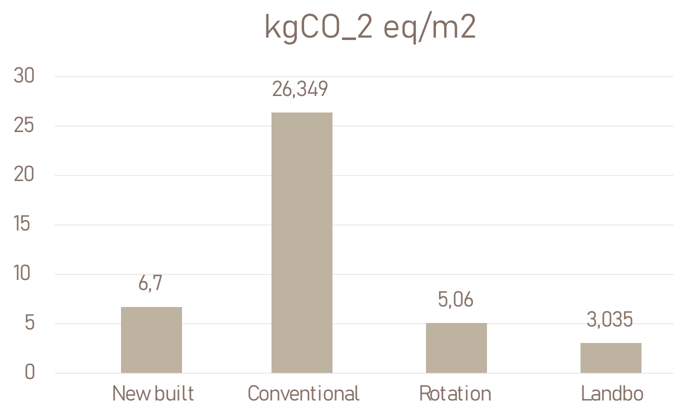


Ill.149: Housing rotation Landbo

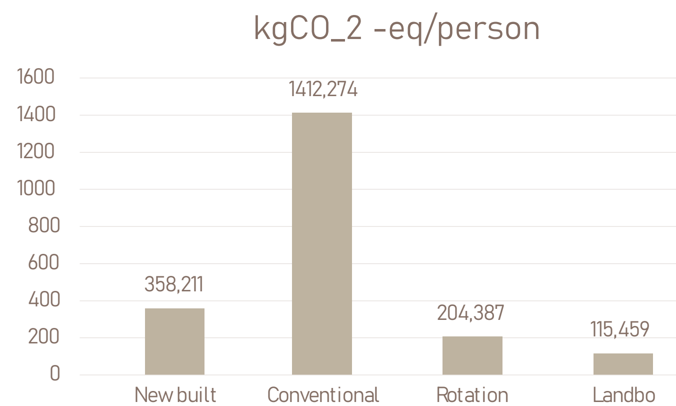
The transformation of an old cattle farm into a residential area required a more significant intervention in terms of materials to create liveable buildings. However, despite the transformation demanding more materials than the other typologies, the housing rotation principle, with Landbo integrated, ensures a lower climate footprint than the three other moving principles (see ill. 150 & 143). See calculations in Appendix 12: Calculations for rotations. This is due to the use of bio-based materials in Landbo, which resulted in a reduction of global warming potential by approximately 68% compared to mineral wool (Appendix 18: Re-insulation).

When comparing Landbo to the different moving principles based on the number of people living across the various typologies, Landbo ensures the lowest climate footprint. (see ill. 151 & 152) This is due to more people living together in a smaller area, with a variety of housing units provided to suit different people's life situations.

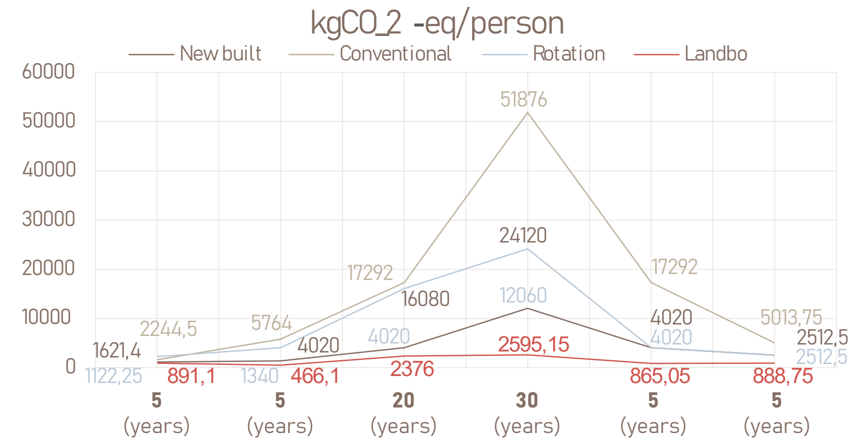
It can be debated whether this scenario of housing rotation realistically reflects people's moving patterns. As illustrated by the conventional moving principle, people are accustomed to living in the same home for long periods, with the specific home becoming an important base of life. However, as the results show, the implementation of housing rotation would improve the climate footprint. Therefore, it is crucial to shift people's mindset towards embracing new housing typologies that better suit their life situations, in order to promote development through transformations and renovations that reduce the climate footprint of people's moving patterns.



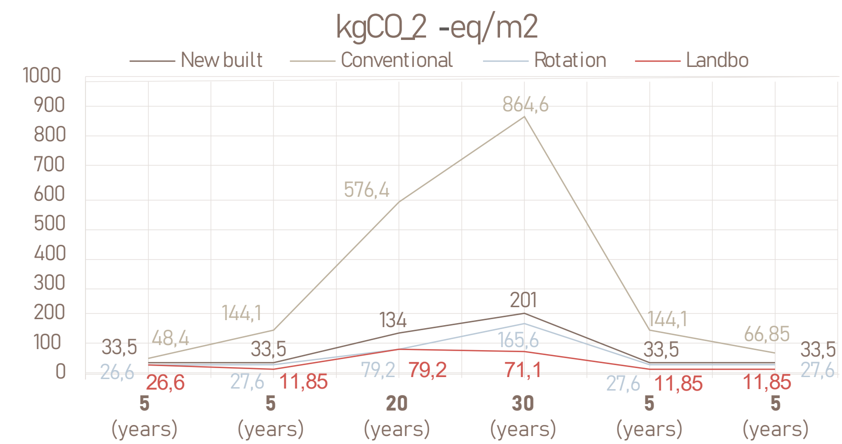
Ill.150:Comparison graph I



Ill.151: Comparison graph II



Ill.152: Comparison graph III



Ill.153: Comparison graph IV

conclusion

Through an integrated design process, this thesis has developed a design proposal based on various literature studies, investigations, and analyses derived from both architectural and engineering approaches. The design proposal, Fællesskabet Landbo, presents a socially and environmentally sustainable transformation that honours the village of Råby and its residents. By employing the principles of housing rotation, an investigation into different moving principles was conducted to examine the environmental potential of reducing the climate footprint through the implementation of diverse dwelling typologies, where more people live on fewer square metres.

Fællesskabet Landbo, a community-based housing association, is a transformation project of an old cattle farm, where the farm's buildings have been repurposed for new functions. The traditional wing farm was assessed as worthy of preservation through the SAVE analysis and insights from Danish farm history. As part of the transformation, this element of the cattle farm has been converted into housing units of various sizes, along with rentable rooms for visitors and a common house for the residents to gather. Between these elements, the existing gravel courtyard has been transformed to a new green common area where residents can socialise. In the fragmented utility buildings positioned across the sloped terrain, functions such as a work- and repair shop along with an open garage with integrated solar panels have been introduced. These transformed building masses now accommodate functions that do not require heating, providing spaces for residents of Fællesskabet Landbo to engage in hobbies and projects.

To guide the design process, four generic user groups were established to inform the development and investigation of the principles of housing rotation. In addition to these user profiles, fictive plans and moving scenarios were created to further explore the concept of housing rotation. The life cycle assessment methodology was incorporated to evaluate the climate footprint associated with different moving scenarios.

The thesis concludes that the implementation of housing rotation within a city like Råby is a sustainable solution for village development. By introducing various typologies that meets different user's need and changing needs, a thriving community can flourish. The transformation of the cattle farm has been executed in a delicate manner that respects the history of the farm and the surrounding rural land.

reflection

Through the education at Aalborg University, the methodology of the integrated design process has been deeply embedded into our approach, alongside problem-based learning. This methodology has been consistently applied throughout all semesters and integrated into each project, allowing it to become a core part of our working process.

For this thesis an element of our approach towards the methodology has changed. The first phase, the problem phase, had to be completely formulated by us, the students, whereas other semesters or projects this has been developed by teachers, semester coordinators etc. While this provided significant freedom to explore personal architectural interests in new ways, it also introduced challenges. Having to work iteratively while developing a problem base for the thesis changed the direction of the project several times. Along researching several new inputs provided the project with information which concretised the framework of the thesis, but also changed the general direction and problem formulation, which created a fragmented process. Constantly, analysis and theories were either relevant or irrelevant, the main topics of the thesis switched.

Working with Nicolai Bo Andersen's approach to transformation, the three principles—historical, technical, and phenomenological—were intended to be evenly integrated into the design, much like Vitruvius' three fundamental topics. The technical aspect, focusing on circularity, including life cycle assessment and housing rotation investigations, was heavily incorporated into the project. The historical component, involving Danish farming history, SAVE analysis, and site analysis, was well integrated throughout the early stages of the project. However, the phenomenological aspect was somewhat underestimated. While two preliminary serial visions provided a sensory experience analysis of the site, more phenomenological considerations were not prioritised during the design phase. Initially, materiality and aesthetics were disable elements in the design of Landbo, but due to time constraints, this aspect was not realized to the desired level of detail and quality.

The implementation of housing rotation contributed to an investigation enhancing the relevance of incorporating the concept as a development factor in villages in Danish rural districts suggested in the report grøn Boligrotation – Vejledning by Forening for Byggeriets Samfundsansvar and Landdistrikternes Fællesråd (Forening for Byggeriets Samfundsansvar og Landdistrikternes Fællesråd (2024))

The approach to the investigation focused only on fictive typologies made through own assumptions and understanding of peoples moving patterns. A more thorough analysis of the peoples moving pattern could have influences the final results. Besides this the investigation only compared the conventional moving principle with the housing rotation principle. The conventional included no energy renovations throughout the main individual's lifetime, whereas the housing rotation only included energy renovated typology cases. To reflect upon this a comparison of worst-case scenario vs. best-case scenario appeared. Since it is not a requirement to energy renovate buildings when moving in or purchasing, a full energy renovation cannot be curtained to happen. It also requires a curtain economic surplus to be able to put the necessary materials into energy renovations of the full envelope.

The implementation of housing rotation contributed to an investigation that enhances the relevance of incorporating this concept as a development factor in villages in Danish rural districts, as suggested in the report Grøn Boligrotation – Vejledning by Forening for Byggeriets Samfundsansvar and Landdistrikternes Fællesråd.

The approach to the investigation focused solely on fictitious typologies, based on assumptions and our understanding of people's moving patterns. A more thorough analysis of people's moving patterns could have influenced the final results. Furthermore, the investigation only compared the conventional moving principle with the housing rotation principle. The conventional moving principle involved no energy renovations throughout an individual's lifetime, whereas the housing rotation principle considered only energy-renovated typologies. To reflect this, a comparison between a worst-case scenario and a best-case scenario was made.

Since it is not a requirement to energy-renovate buildings when moving in or purchasing, a full energy renovation cannot be guaranteed. It also requires a certain economic surplus to implement the necessary materials for a full energy renovation of the building envelope.

Regardless, the investigation into housing rotation provides valuable insights into the potential for sustainable development in rural Danish villages. While the findings are based on assumptions and comparisons, they highlight the importance of integrating energy renovations within housing rotations. Overall, the design, Fællesskabet landbo, is a sustainable solution with integrated elements of these learnings.

perspective

To place the project and its learnings into a broader context, a deliberate discussion of the thesis and its content is presented in this section. This master's thesis aimed to create a design proposal in response to Randers Municipality's idea competition, "It's So Lovely in the Countryside" (Danish: Det er dejligt på landet). The goal of the competition was to propose an innovative transformation that embraced Denmark's rural landscapes. Through this project case, the thesis presents Fællesskabet Landbo, an environmentally and socially sustainable solution that integrates the surrounding village of Råby by implementing the principle of housing rotation.

Through the methodology of life cycle assessment (LCA) and the estimation of moving principles, along with energy assessments, it was possible to illustrate the sustainable advantages of housing rotation. By using LCA as part of the strategy to investigate housing rotation, the climate footprint was evaluated not only for the building elements of the transformation but also for the individual's moving patterns.

Sustainability is a highly discussed issue in both building practice and society. A new threshold for life cycle assessment (LCA) will take effect on June 1, 2025, introducing a stricter framework for buildings and architecture in Denmark. While new buildings will be designed with this in mind, as this thesis concludes, existing buildings must also comply. Energy renovations are essential for reducing operational energy demand, which currently contributes to a significant climate footprint. New building owners are generally more inclined to renovate buildings when they first move in (Landdistrikternes Fællesråd & Forenet Kredit, 2025). In villages like Råby, where resident turnover is low, existing buildings are often not updated to meet current standards and requirements. As such, the need for housing rotation in these villages is necessary—not only to support the community but also to ensure diverse, adaptable housing options for various residents.

The design proposal, Landbo, serves as both a case design solution for Randers Municipality's idea competition on transforming agricultural buildings and an academic investigation into housing rotation through circular building principles. Building on this foundation, the insights gained from this thesis can be applied to other transformation projects in villages across Denmark. The principle of housing rotation could be further explored in different contexts, where factors such as transportation or other scenarios are integrated.

Ill.154: Own picture cattle farm

thank you

As a final remark, we would like to say thank you to Randers municipality for their idea competition that provided the basis for the framework for this thesis along with the sparring that assisted the discovery of the project farm in Råby. Another special thanks to the farmer in Råby for the collaboration that made the whole project possible.

Ill.155: Overview Landbo

litterature

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illustration

appendix

01 planning conditions

As of now, no local plan has been developed for the area of Råby where the farm is located. To gather information about the planning conditions of Råby, the latest municipality plan from 2021 is examined instead.

The Municipality of Randers states in its municipality plan that they aim to create the best possible conditions for securing and developing the quality of the urban areas, the rural land and the natural environment in a sustainable manner. (Randers Kommune (2021))

The plan outlines various goals and guidelines, supported by the UN's Sustainable Development Goals, to ensure a proper development of the municipality. Some of these goals apply to small cities such as Råby. Råby is part of the character area named 'The open widths' (De åbne vidder), where the objectives is to ensure city development with a focus on local identity, cultural heritage and quality forstering strong local communities. The aim is to make these cities attractive places to live in by ensuring a variety of dwelling types to accommodate different residents, while also increasing the access to natural and recreational areas. (Randers Kommune (2021))

To ensure appropriate land use and development, the municipality has established framework conditions for certain areas. Råby falls within the framework area 5.15. BE.1, which designates the general use for this area as a mixture of dwelling and business. The area is classified as a rural zone (landzone) and should therefore function as a village with open-low dwelling typology. Additionally, allowing for business activities, vacation homes and leisure activities, together with public and cultural institutions. When constructing new buildings, specific requirements must be taken into account, particularly when considering the transformation of a farm. (Randers Kommune (2021))

- Building regulations
- Maximum plot ratio: 30 %
- Maximum number of floors: 1,5
- Maximum building height: 8,5 m

Regarding the municipality's focus on cultural heritage, Råby is classified as a city with moderate preservation value, meaning that the local cultural heritage and historical identity are considered worth of preservation. As for the cattle farm, the municipality has identified three of its buildings as having potential for preservation. (Randers Kommune (2021))

This concludes that the municipality, in general, places a significant focus on the development of the small cities and has an interest in preserving the cultural heritage and local identity. Råby has the potential to strengthen its local identity by preserving elements that emphasises its cultural heritage, making it a more attractive place to live. At present, the municipality sees a potential in preserving some of the cattle farm's buildings.

02 cultural environment

Since a greater understanding of the city's history and structure has been achieved through the previous examinations, this section will conclude of what meaning Råby has as a cultural environment and which aspects and qualities the city possesses. This will be achieved with inspiration from the method of Screening of Cultural Environment (SAK) developed by Aarhus School of Architecture. SAK is a method for analysing the cultural qualities of several cities, comparing them, and ultimately selecting the most relevant ones for further planning (Aarhus School of Architecture, 2019). In this case, the focus will solely be on defining Råby as a cultural environment, rather than several cities.

According to the method description a cultural environment is a defined area where its societal development is distinctly expressed in its physical structure, contributing with historical and cultural identity within the municipalities. (Aarhus School of Architecture, 2019). The municipality of Randers has already conducted a SAK-screening of relevant cities including Råby, but it is determined to base this section on own examinations and experiences of the city. (Aarhus School of Architecture, 2020)

Values

Råby's cultural-historical value is visible in the centrally located village pond and some of the preserved surrounding farms. However, several of the original farms have been replaced by smaller dwellings, which showcases the development of the village. Architecturally, Råby remains as a small village with a low-rise building structure surrounded by open fields (see structure analysis). The traditional wing farms still have their impact on the city's identity, together with buildings such as the church and local hall, though some have been modified. The preserved experience of a low-rise village structure that oriented towards the central pond, contributes to Råby's strong architectural integrity.

Qualities

The village pond serves as an attraction, being the largest in northern Europe, but Råby lacks other significant landmarks. Regarding to settlement patterns, the structure analysis indicates that the city mainly has single-family houses and limited rental housing opportunities. The main occupancy is farming, and the city has a small grocery store, but due to its size and remote location it has little potential for other local shops. Råby holds significant cultural value due to its attraction of the public pond and surrounding village structure with some preserved traditional wing farms.

Råby - Cultural environment assessment	
Values	
Culture-historical	**4**
Architectural	**2**
Integrity	**4**
Qualities	
Tourism	**2**
Settlement	**2**
Occupation	**2**
Culture	**4**

1: Very low **2**: Low **3**: Medium **4**: High **5**: Very high

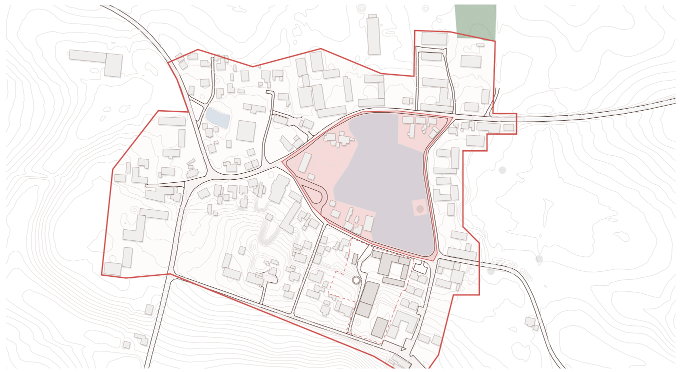
Råby, as a cultural environment, possesses strong worth in its historical and cultural identity. Elements such as the pond, the preserved traditional wing farms and the village structure contribute to the city's identity and should be supported through preservation and integration of new functions. For further investigation, it will be relevant to explore the implementation of additional attractions for the city and different dwelling types allowing a more diverse types of residents.

03 city image

For a deeper and more fundamental understanding of the city's layout and elements, a simple analysis of Råby based on Kevin Lynch's 5 elements of the city is conducted. The purpose of this initial analysis is to establish an understanding of the city's structure based on fundamental architectural principles, fostering a common understanding of Råby as a whole. The 5 principal elements are paths, edges, districts, nodes and landmarks. (Lynch, K (2002))

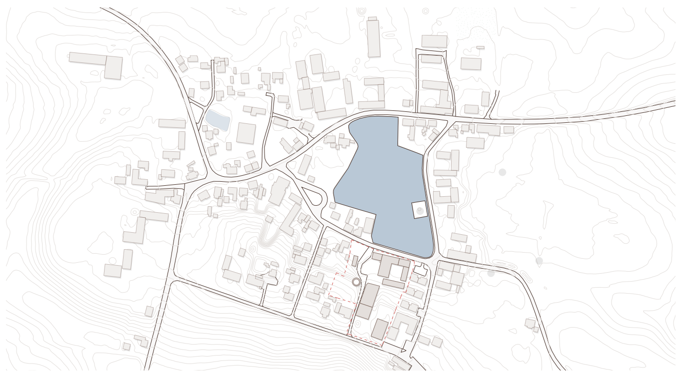
Edge

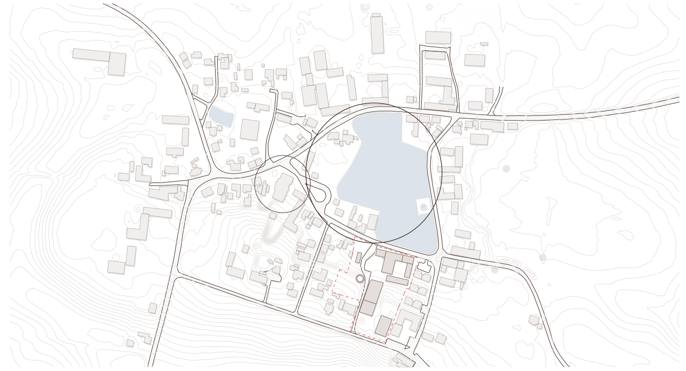
Two edges of the city are able to be identified. The first is the pond's water edge, which serves as a physical boundary, regulating the internal flow of the village. The second edge is the city boundary, which differentiates the city structure from the surrounding fields.



Landmarks

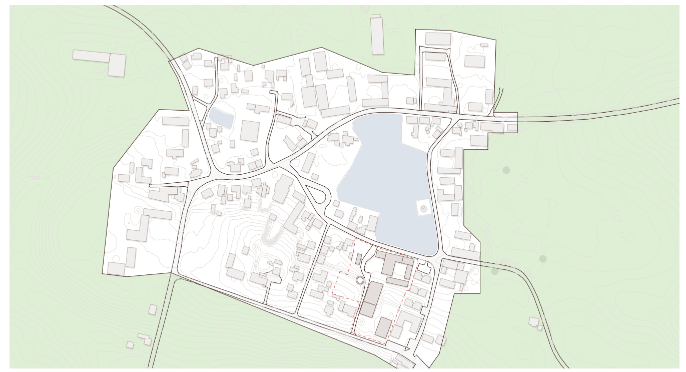
As previously mentioned, the village pond has a significant impact on both the city's structure and history. Being the largest village pond in Northern Europe, the pond itself serves as an attraction, drawing outsiders to Råby.





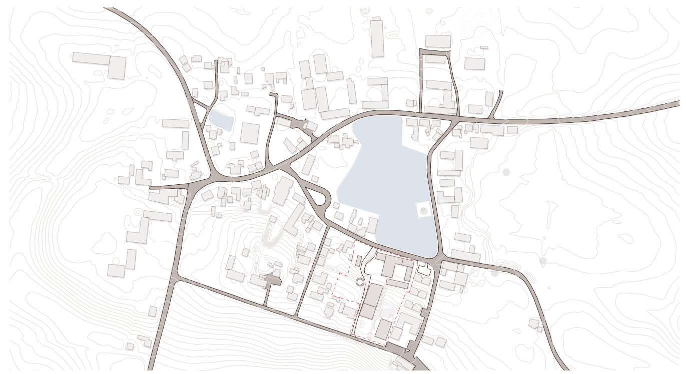
Nodes

Being a central element of the city, that has formed the building layout, the village pond makes a node of physical movement. Moving from one edge of the city to another, one will most likely result move along the pond. A secondary node is the location of the grocery store, gas station and posting box office, where Råby's locals access their essential services. .



Districts

Divided by the city edge two types of districts emerge: an urban district and a rural district. These are supported by the structure analysis, the building structures that forms the city image, and the rural district, dominated by the many fields. This clear division of the districts enhances the function of the liveable city and the open fields. .



Paths

The paths of the city are defined by the roads. There are four main roads leading to the city and a network of internal roads within. Most notable, are the ones following the village pond, which emphasizes the roundabout-like system and reinforces the pond as an important part of the city's identity.

04 mirco climate

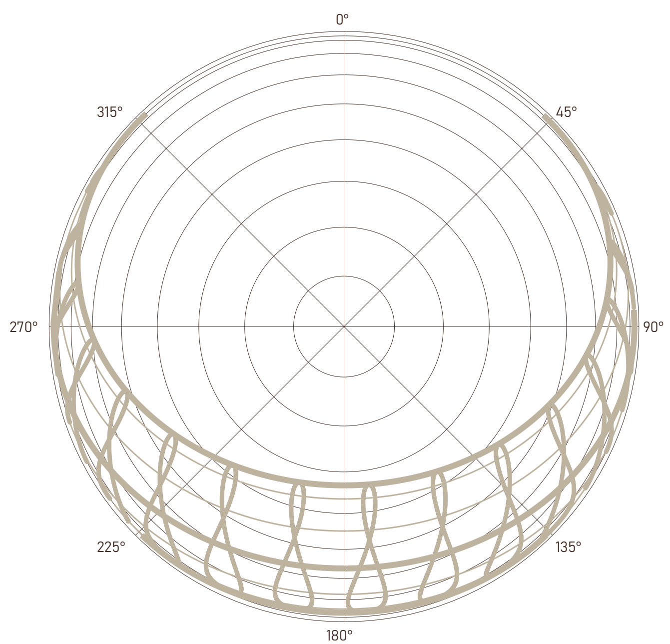
To form an understanding of weather conditions on site a series of examinations and evaluations are conducted. This will inform the design process of the plan programming, where different rooms are to be placed, and especially help to decide which urban elements and functions are to be included and located around the farm.

For this section data from climatetools (https://clima.cbe.berkeley.edu/) are being used and the EPW file for the data is from Hald Vest weather station, which is located 12 km from the site in Råby.

For the investigation the rainwater flow and noise distrubance were also examined, but did not contain any relevant issues at the site.

SUN

The sun's path is essential for designing a building. Various room's location dependent on the sun. For this project, the farm location is slightly rotated 13 degrees. Due to the project being a transformation project the building's current orientations are to be kept, but the interior and window openings must be considered along with the sun path. This is due to the importance of ensuring access to daylight as well as considerations of indoor comfort and energy efficiency.

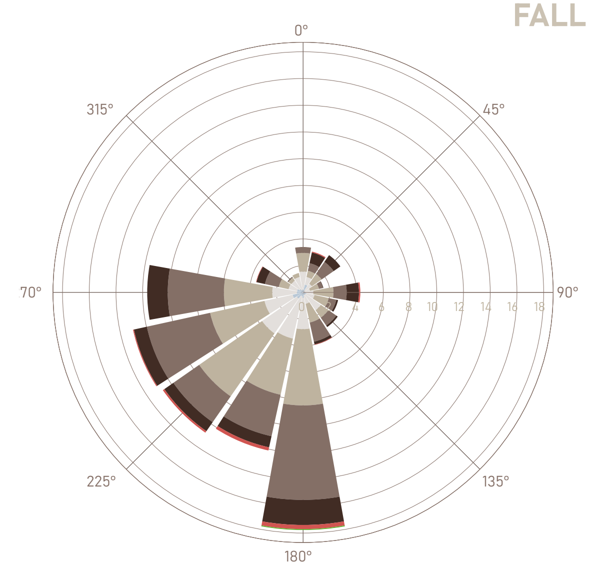


WIND

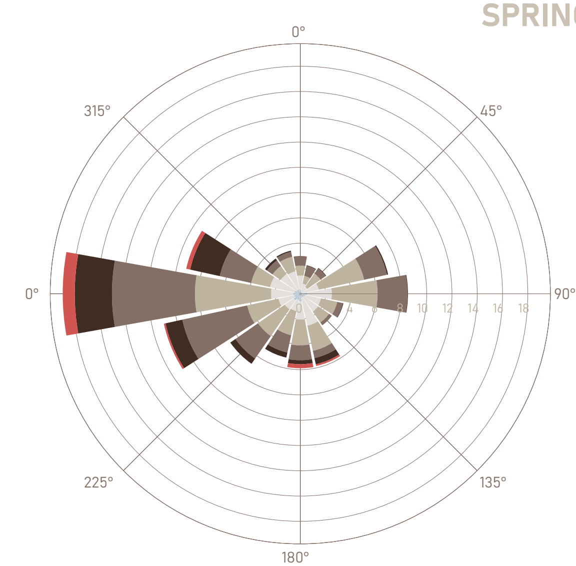
The wind condition on the cattle farm is important to investigate in order to design for natural ventilation and comfortable outdoor spaces. From climatetool four seasonal wind roses has been extracted. These generally show that the main wind direction is from the west, but in autumn this changes as the dominant wind comes from the south. Generally, there is moderate wind breeze, where the highest measured wind 13,8-17,1 m/s which is a strong wind, this only occurs in the winter period.

From this information, outdoor spaces for stay, such as terraces must be shieled from the western wind. Window opening must be placed strategically from the interior layout along with the possibility of having a natural cross ventilation though living spaces.

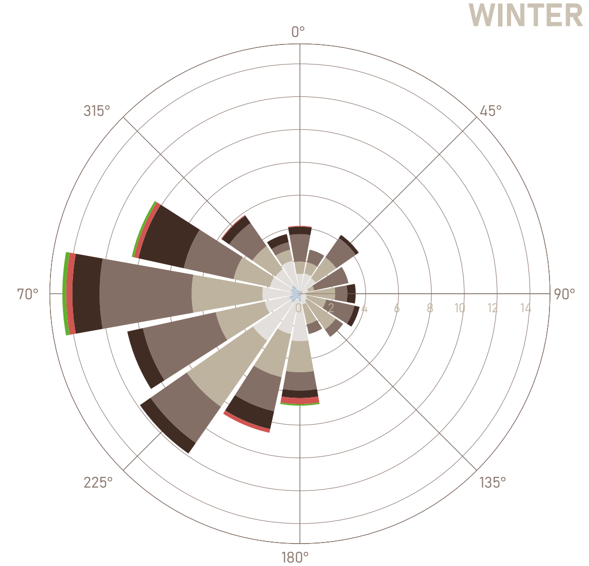
FALL

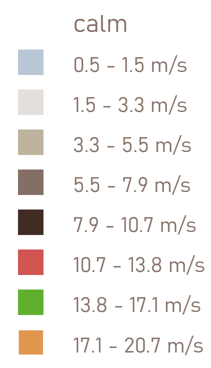


SPRING

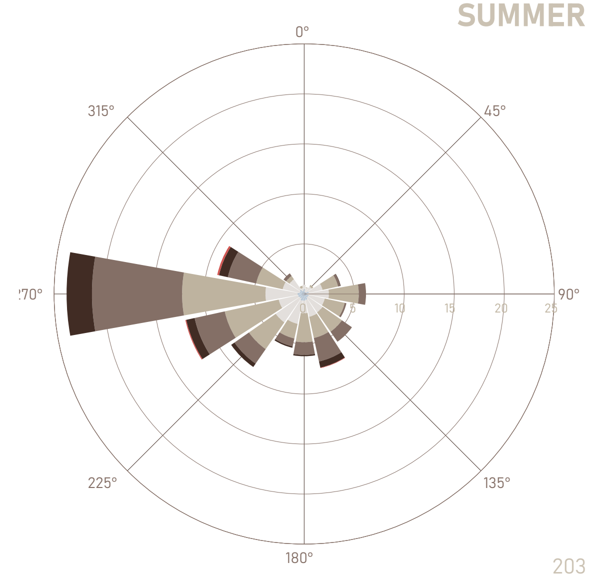


WINTER





SUMMER

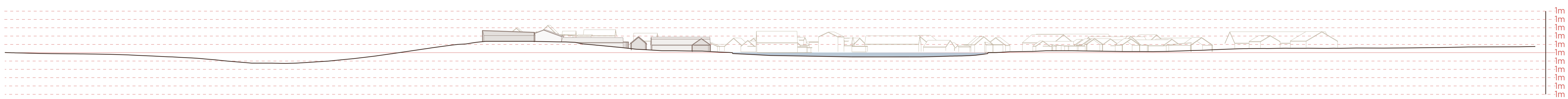


05 city profile

The previous analysis visualised the different elements of the city Råby and described the connection between these. This analysis will briefly examine the city profile, where proportion and silhouette of the city are analysed.

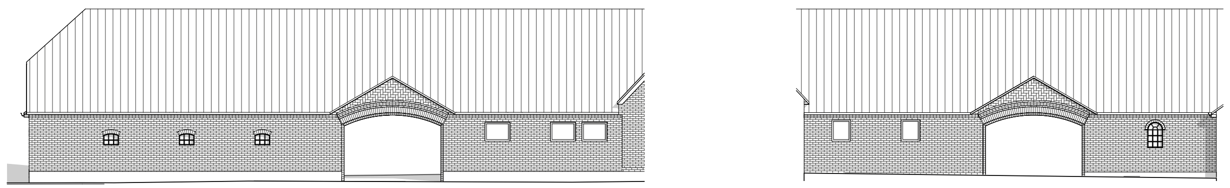
The city's vertical structure is very interesting to look at. Overall, the buildings within Råby are only one story, maximum two stories in certain houses, which could suggest a relatively flat layout. However, this is interrupted by the natural terrain, which defines a dynamic city image.

Looking at the placement of the cattle farm, it is clear that it is situated on top of a small hill. With a steep slope towards the south, overlooking the fields, and a gentle slope towards the north and the pond, the farm occupies a central and prominent location in the landscape.



06 original facades

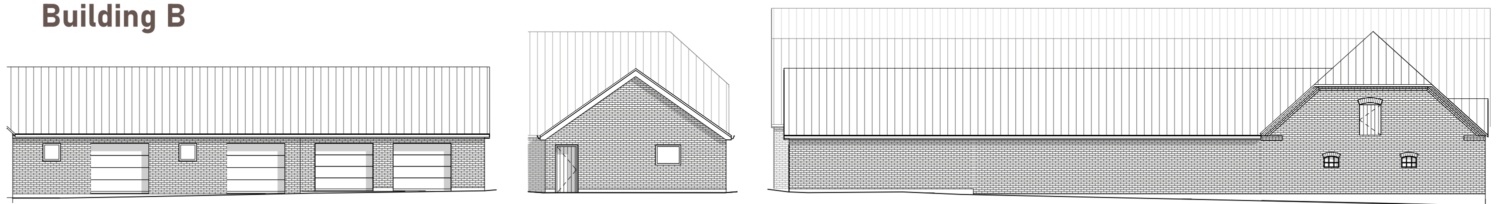
Building A



North elevation: 1:300

South elevation: 1:300

Building B



West elevation: 1:300

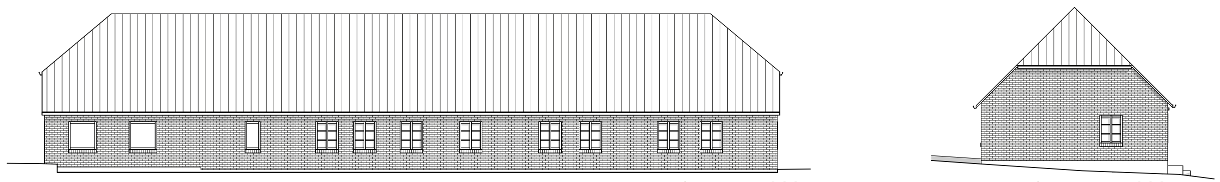
South elevation: 1:300

East elevation: 1:300

Building C

North elevation: 1:300

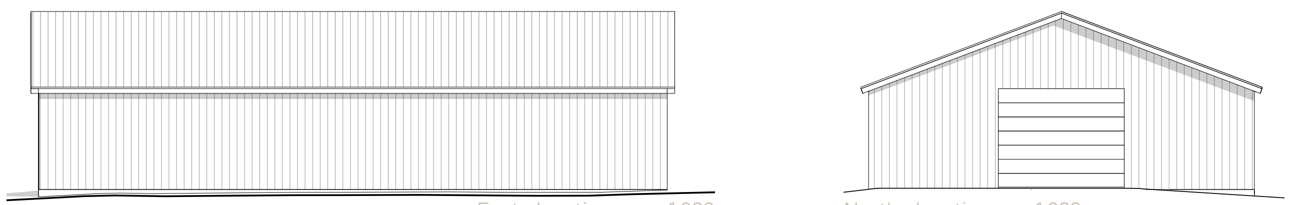
West elevation: 1:300



South elevation: 1:300

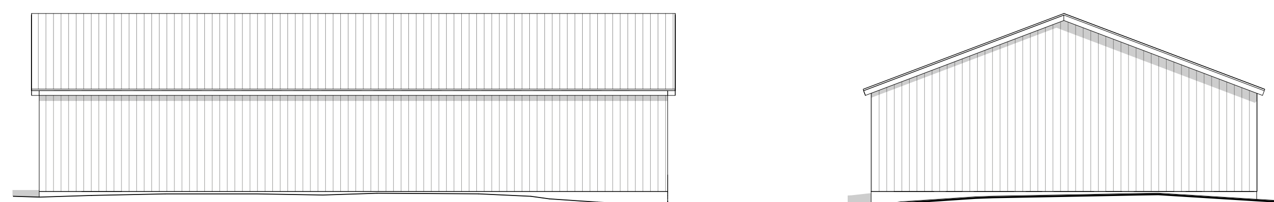
East elevation: 1:300

Building D



East elevation: 1:300

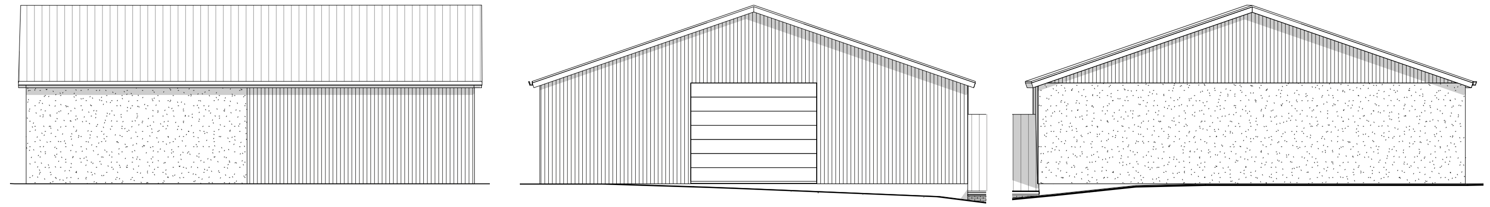
North elevation: 1:300



West elevation: 1:300

South elevation: 1:300

Building E

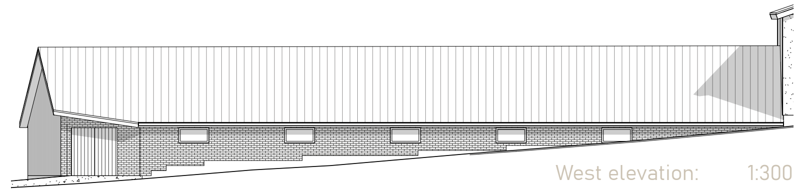


South elevation: 1:300

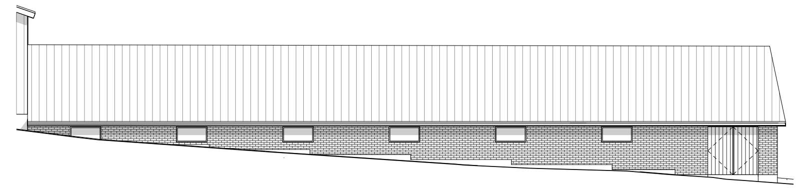
East elevation: 1:300

West elevation: 1:300

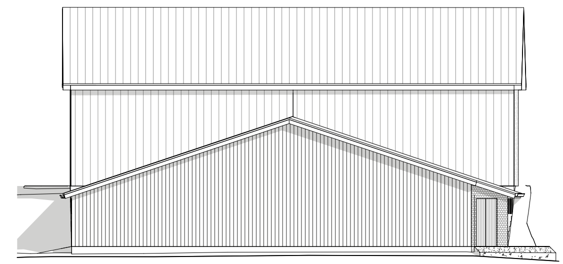
Building F



West elevation: 1:300

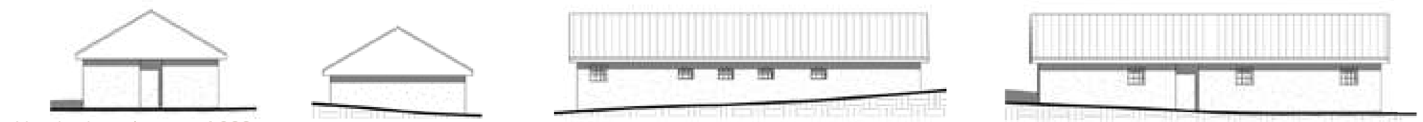


East elevation: 1:300



North elevation: 1:300

Building H



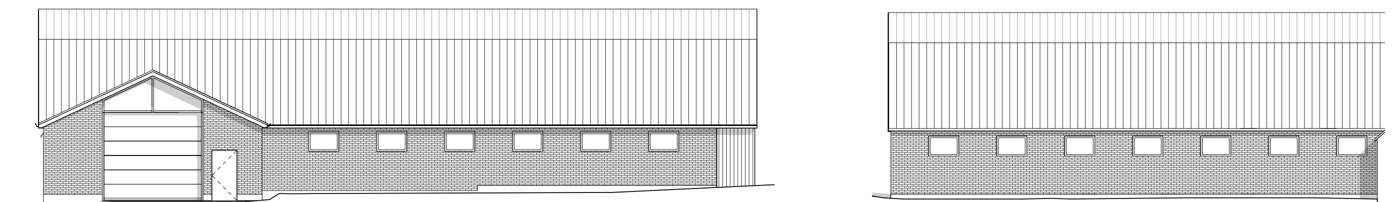
North elevation: 1:300

South elevation: 1:300

West elevation: 1:300

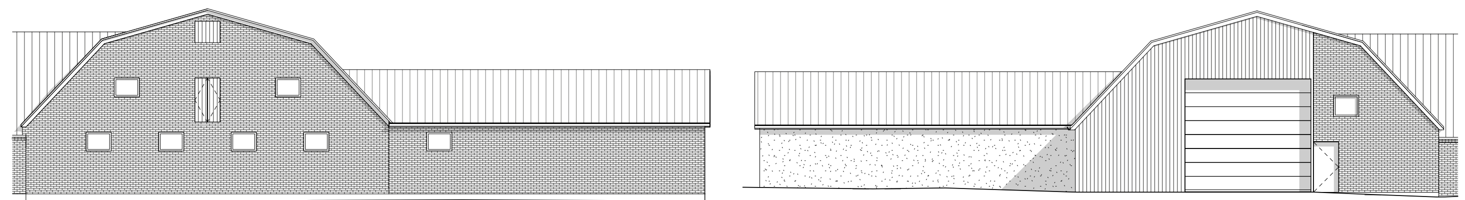
East elevation: 1:300

Building I + J



West elevation: 1:300

East elevation: 1:300



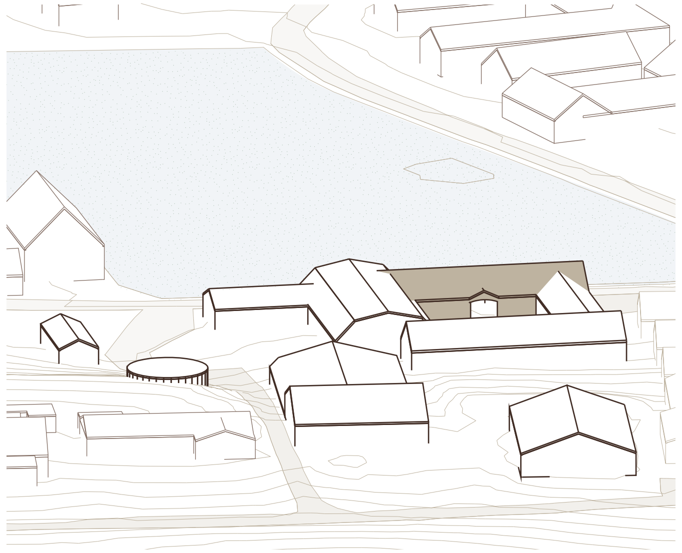
North elevation: 1:300

South elevation: 1:300

07 SAVE

BUILDING **A**

Building A is built in several stages, the first note of construction is in 1884 followed by some renovations in 1940. It was originally built as a grain stock, where grains such as oats and rye were sorted and stored. The building was in use until a few decades ago, when the current farmer stopped the production of plant cultivation.



Evaluation

With the buildings originality including traditional curved windows and mullioned windows, together with brick details and curved brick cornices, gives it historically significant and cultural worth to preserve.

Cultural-historical Value

As mentioned, the building was initially used for grain storage and was the first element of the farm that was in full production. Building A contains one of the key icons of the farm, the entrance port, that is the main opening towards the city and village pond. Creating a strong visual and functional connection between the farm and its surroundings. This element plays a significant role in defining the farm's identity within the village structure.

low	low/medium	medium	medium/high	high
				●

Architectural Value

The building consists of yellow bricks and features some decorative cornices and other brick ornaments above the entrance port. Additionally, other elements such as the old window openings also has brick details around it. These architectural elements create an interesting facade with visual pleasing patterns.

low	low/medium	medium	medium/high	high
				●

Enviromental Value

Building A is the element of the farm that faces the city. It is placed directly towards the village pond meaning that it is often visible from different angles of the city. Especially the entrance port is easy to recognise in the city image, as it particularly stands out as a distinctive feature reinforcing the farm's strong presence within the village.

low	low/medium	medium	medium/high	high
				●

Originality

The building is original and has retained its historical architectural character with elements such as its yellow brick facade, decorative cornices, and brick ornaments. The entrance port also remains as an original element.

low	low/medium	medium	medium/high	high
				●

Condition

Due to the originality the building's facade is worn and traces of patina is visible along with this some of the exterior bricks has been replaced due to damage. Besides this, the building is in fine condition for its current use.

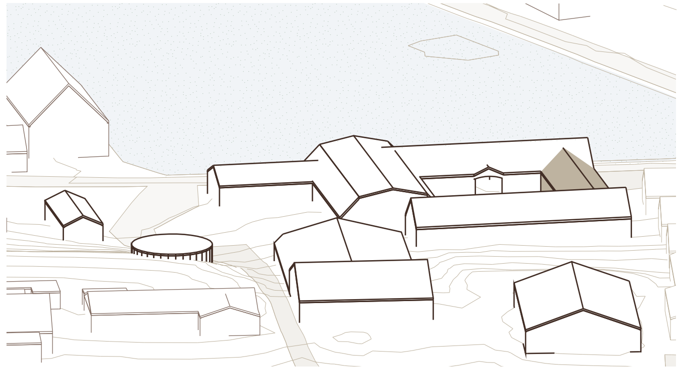
low	low/medium	medium	medium/high	high
		●		

BUILDING **B**

Building B currently serve as a garage for parking cars and smaller vehicles. The building has within the last couple of years undergone a renovation to modernise it into a functional and mechanical garage. There are three garage port openings towards the courtyard, and a blank brick wall towards the city.

Evaluation

The building appear as a clear contrast in the four-wing farm with its modernised facade openings and lacks direct reference to the original building. But since the building has been renovated taking base in the original footprint letting the farm structure of a four-wing farm being maintained, together with preserving the facade as a yellow brick facade the building, it still respects its historical worth and should therefore be preserved.



Enviromental Value

The building differentiates the site with the rest of the city, as its longitudinal and closed shape creates a physical barrier to the neighbouring houses. This separation enhances the courtyard within the four-wing farm, while also encloses the spatial relationship between the farm and its surroundings towards east.

low	low/medium	medium	medium/high	high
		●		

Cultural-historical Value

The current building is constructed in 1965 and is part of the four-wing-farm that creates the inner courtyard. Originally the building functioned as a barn for horses, according to the current farmer, but as the technical development of farms occurred the need for horses disappeared.

low	low/medium	medium	medium/high	high
			●	

Originality

The current building is renovated in 1965, but it still reflects the farm's originally and thereby historically footprint. Preserving the spatial organization and architectural identity of the site.

low	low/medium	medium	medium/high	high
	●			

Architectural Value

There is a clear visible contrast in the construction where building B connects to the rest of the wing-farm. This is especially noticeable in the socket meeting, where the difference between new and old appear. Important to note that the building has been renovated with respect to the rest of the four-wing-farm giving it a clear reference to the original architectural expression.

low	low/medium	medium	medium/high	high
		●		

Condition

The building is in a good condition due to the latest renovation as long as the building contains similar functions within.

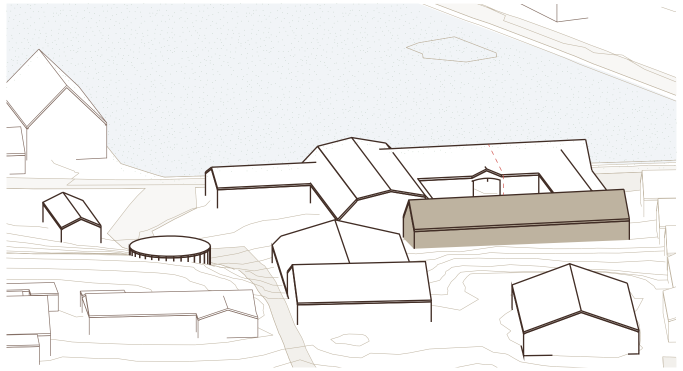
low	low/medium	medium	medium/high	high
				●

BUILDING **C**

This building is the housing wing of the farm, the current farmer living there has completely renovated this wing in 2015. The renovation mostly modernised the interior, but also elements of exterior has been updated.

Evaluation

Since this building appear with a traditional rhythmic expression with mullioned windows and brick cornices and the building is maintained on the original footprint being part of the historical four-wing farm, the building should be preserved.



Cultural-historical Value

This wing has always served as a housing section and living space of the farm. It is placed directly opposite of the entrance port, which makes the housing wing the first element to see when entering through the port opening.

low	low/medium	medium	medium/high	high
			●	

Architectural Value

The building is a traditional farmhouse featuring mullioned windows that creates a regular rhythm in the facade. Additionally, brick cornices contribute to a decorative pattern, enhancing the architectural character of the structure. The overall facade expression is symmetrical and regular.

low	low/medium	medium	medium/high	high
				●

Enviromental Value

Building C is a part of the four-wing-farm structure. It divides the oldest part of the farm with the more industrial part. Due to the housing farm being the first element to see is it important that the building relates to the rest of the wing-farms architectural expression as it is part of the visual perception from the village.

low	low/medium	medium	medium/high	high
				●

Originality

The renovation of the building has been carried out with great care and respect for the existing architectural heritage of the site, ensuring its historical character.

low	low/medium	medium	medium/high	high
			●	

Condition

The exterior and interior of the building are in good condition and require no maintenance at this time, due to the renovation by the farmer.

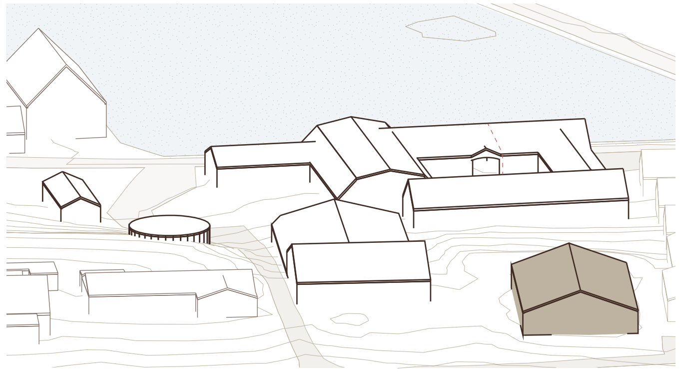
low	low/medium	medium	medium/high	high
				●

BUILDING **D**

Building D is a steel barn, serving as a workspace barn. It is located on the top of the hill next to building E. It is built in 1959 and has voluminous building mass allowing tractors and other larger vehicles to enter.

Evaluation

The building has a clear reference to the development of the farming industry with the implementation of more industrial buildings. Its placement towards south makes it responsible for the site's identity when entering from this side. Therefore the industrial and functional shape and expression is worth preserving to emphasise the historical value of the farming industry.



Enviromental Value

With no openings other than the large port the building has a very closed facade towards the surrounding. The buildings' location on top of the hill provides it with a statement spot, that must be taken into account.

low | low/medium | medium | medium/high | high

Cultural-historical Value

It is a simple barn that illustrating today's farming industry with an industrialised and functional workspace. The building is easy to access coming from the fields placed towards the south which is essential for the everyday operation of the farm.

low | low/medium | medium | medium/high | high

Originality

The barn is the original from 1959 but contains traces of some replacements of the exterior facade cladding. The structure as well as footprint is the completely originally.

low | low/medium | medium | medium/high | high

Architectural Value

Like the machinery barn in building E this workspace barn emphasises a functional architectural expression. This related to a practical open layout and the materials used for construction that is easy to maintain and replace if needed.

low | low/medium | medium | medium/high | high

Condition

Despite being an old steel building the facade panels are in good condition same as the internal steel beams. These must be implemented in the investigation of the circular building principles when designing.

low | low/medium | medium | medium/high | high

BUILDING **E**

Building E was built in 1970's and is also a machinery barn that consists of steel walls, together with concrete walls and foundation. It rises on top of the hill that occurs though the site and is dominant in the landscape.

Evaluation

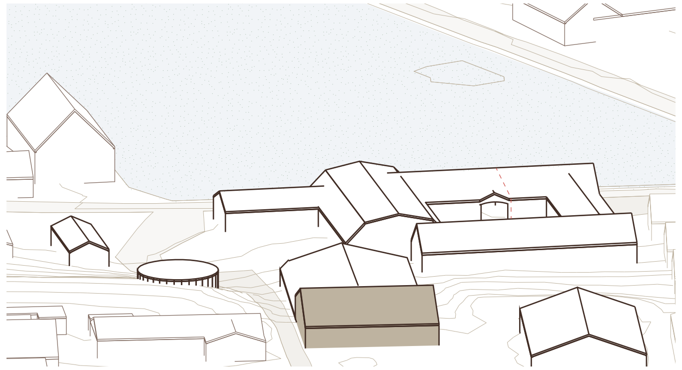
This building also has a clear reference to the development of the farming industry as building D given its also industrial identity. Therefore this buildings industrial and functional shape and expression is also worth preserving like building D.

Cultural-historical Value

This building also enhances today's farming industry with an industrialised and functional workspace. Besides serving as a machinery barn building E is also the operating space for feeding the cows within building F. They are internally connected, which is important for the everyday activities.

Architectural Value

Building E does emphasise a functional and rational expression but contains not decorative elements or architectural details. There is a strong visual split between building F and E in the difference of materials and height, which create an interesting contrast in the facades.



Enviromental Value

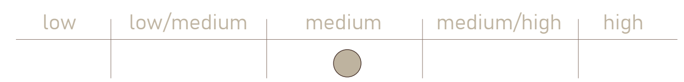
Building E is placed approximately 3 metres above the building F, this is due to the terrain slope that rises through the site. Building E faces towards building D and both are placed evenly high on the top of the slope, which also gives it a statement spot, that must be taken into account.

Originality

The barn is the original from 1970 but contains traces of some replacements of the exterior facade cladding. The structure as well as footprint is the completely original.

Condition

Despite being an old steel building the condition of the facade panels are in good condition same as the internal steel beams. These must be implemented in the investigation of the circular building principles when designing.

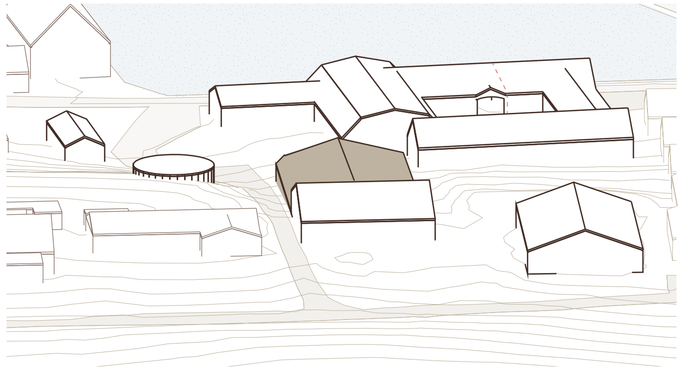


BUILDING **F**

Building F is a cattle barn that is located in connection with building E. It was built in the 1970's and consists of yellow bricks. It is placed within the terrain making the exterior height of the building differ from various positions.

Evaluation

...



Cultural-historical Value

As mentioned, building F is a cattle barn that houses the cows and protects them from wind and weather. Due to the industrialised development of farms this building is placed separated from the four-wing farm to ensure a better hygiene.

Architectural Value

It is clear that the cattle barn's architectural expression relates more to the older buildings of the farm with its yellow brick facade and stringently placed windows openings, whereas the machinery barn is more industrial and functional in its architectural expression. But the metal sheet facade gives it an industrial reference.

Enviromental Value

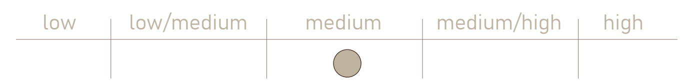
The building is integrated into the natural terrain of the site cutting into the sloped hill to ensure a flat level and allow direct access from the northern end of the site.

Originality

The cattle barn is built back in 1977 and are in its complete original state.

Condition

Due to time and usage, the building shows some signs of damage on the facades. This, unlike the other buildings, consists of many different materials, that are of different conditions.

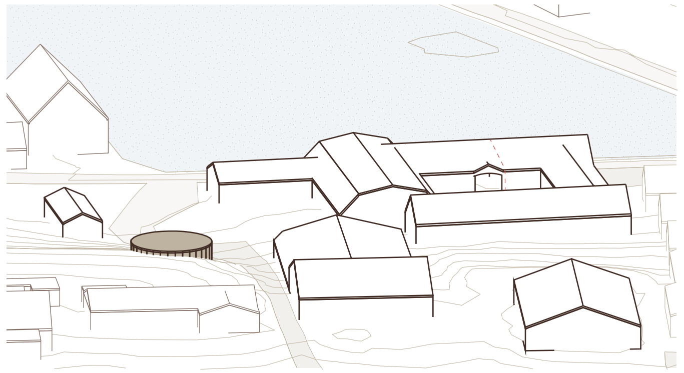


BUILDING **G**

Building G is originally a slurry tank which currently are closed off and not in use, instead it functions as patio for stays and a great view over the village pond.

Evaluation

The slurry tank and its rounded shape is worth preserving due to its reference of being part of the industrial farming industry.



Cultural-historical Value

The slurry tank refers to the farm's identity of being an operating industrial farm allowing the farmer to collect and storage slurry on site.

low	low/medium	medium	medium/high	high
				●

Architectural Value

The tank consists mainly of concrete walls forming the rounded shape. Concrete details are placed on the side of the wall to strengthen the construction. The round shape defines its earlier function and refers to the farming industry.

low	low/medium	medium	medium/high	high
			●	

Enviromental Value

Half of the tank is built into the terrain placed up against the sloped hill. This allows direct entrance on to it when coming from the top of the hill. Its height and placement ensure a great view towards the village pond when standing on the tank.

low	low/medium	medium	medium/high	high
				●

Originality

Even though the tank is currently not in use it has been preserved in its original state only adding a concrete cover and a wood railing on the top giving it a new function.

low	low/medium	medium	medium/high	high
				●

Condition

Overall the slurry tank is in great condition only a little patina developed by weather conditions is visible in is concrete walls and top cover.

low	low/medium	medium	medium/high	high
		●		

BUILDING **H**

Building H is built in 1990 and functions as a hen-house and storage of materials for the hens.

Evaluation

Since the building is placed separated to the rest of the farm and has little architectural references to the farm general architectural industry this building is not worth preserving.

Cultural-historical Value

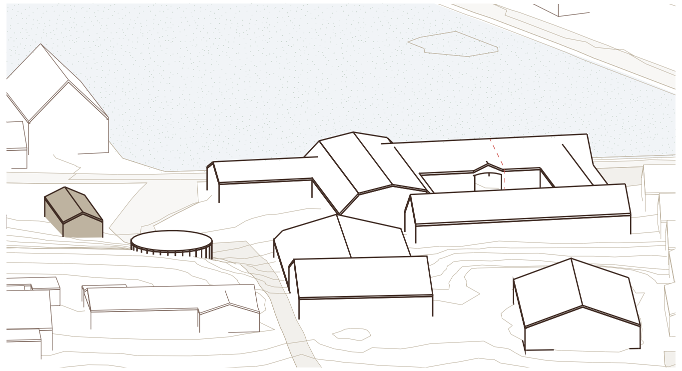
The building is not that old and have little reference to the farming industry other than being a small henhouse.

low	low/medium	medium	medium/high	high
				●

Architectural Value

The building stands with white plastered brick facades and blue wood details in the roof, the doors and the win-dows. This building has no architectural reference to the rest of the farm's architectural identity.

low	low/medium	medium	medium/high	high
			●	



Enviromental Value

The building is placed at the bottom of the hill up against a fenced area for the hens to be within. The building is placed separated from the rest of the farm.

low	low/medium	medium	medium/high	high
				●

Originality

The building is not that old and stand as its original state since being built.

low	low/medium	medium	medium/high	high
				●

Condition

The plastered brick facade has visible signs of patina due to being exposed directly to different weather conditions.

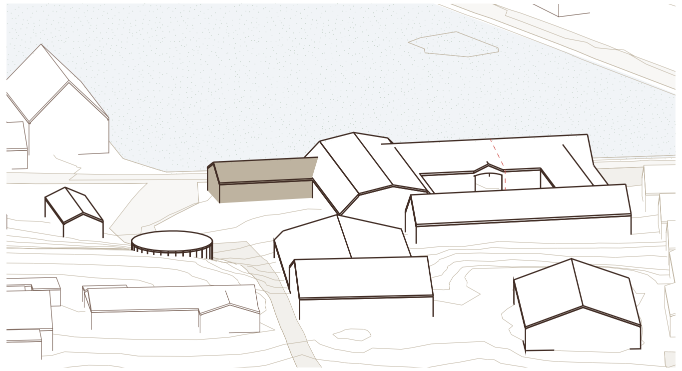
low	low/medium	medium	medium/high	high
		●		

BUILDING I

Building I is built back in 1884 as a extension of building J. It functions as a storage space to store feed and crops etc.

Evaluation

The building has its reference to the farming industry but since it functions as an add on to the four-wing farm and breaks this building structure's identity this building is chosen not worth of preserving,



Cultural-historical Value

As mentioned, the building was built to use as storage room for the feed and crops harvested by the farmer. This gave it its relevance in the farming industry.

Architectural Value

The building consists of the same yellow bricks as the rest of the four-wing farm but the south facade stands with a white plastered expression.

Enviromental Value

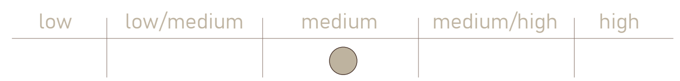
The building i placed as part of the northern facade towards the village pond. But the building breaks the enhancement of the four-wing building structure with its additional extension.

Originality

The building stands as its original construction and state, functioning as an add on to building J.

Condition

The building is in good condition but a has some patina on its facade.

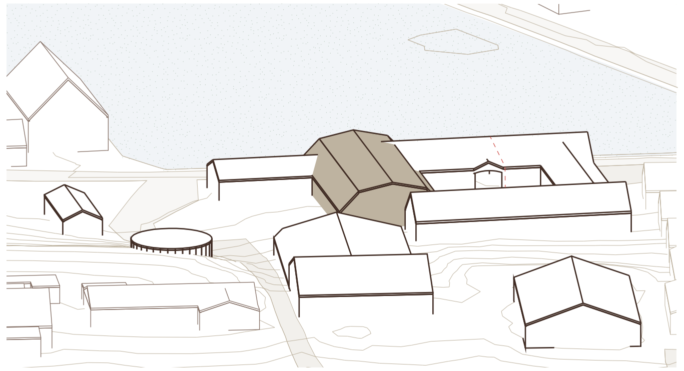


BUILDING **J**

This building was the old cattle barn to have the cattle go inside in the winter. Today the cattle barn is a hybrid space that both functions as a garage and gathering space. .

Evaluation

The building stands as an integrated part of the four-wing farm and is part of the important facade towards the village pond. It has had its relevance in the farming industry since a long time ago gives it historical significance and should therefore be preserved.



Cultural-historical Value

As described before the building was built as a cattle barn with its tall height allowing an open space with a second level deck around the exterior wall to store hay-bales and such for the cattle. This building is part of the original four-wing farm having the cattle barn being close to the rest of the buildings.

low	low/medium	medium	medium/high	high
				●

Architectural Value

The buildings northern facade towards the village pond stands as an important statement piece of the four-wing farm with its tall height and gambrel roof layout and rhythmic windows opening pattern. It facade consist of yellow bricks as the rest of the farm letting it identify with the rest of the buildings and being a part of the four-wing farm.

low	low/medium	medium	medium/high	high
			●	

Enviromental Value

This building is the last element of the farm that faces the city. With its placement directly at the village pond and high facade, this is also often visible from different places of the city.

low	low/medium	medium	medium/high	high
				●

Originality

The old cattle farm was a part of the original four-wing structure. The element must be included in the design of the farm in order to determine the importance of preserving the different buildings.

low	low/medium	medium	medium/high	high
				●

Condition

Since the buildings stands as original visible tracks of use and patina can be seen in the facade, which could require maintenance.

low	low/medium	medium	medium/high	high
		●		

08 Interviews

In the early process of achieving an understanding of Råby seen from the perspective of the locals, two interviews were conducted. The first one was with the owner of the cattle farm, a 75-year-old famer that was born at raised on the farm. The second was with the chairman of the local association within Råby. Both provided informative knowledge that can both be used in the investigation of the city, the local life and assist determining the potential users of the site. Seen below, the highlighted insights provided from these interviews are briefly presented.

Along with these interviews another interview was conducted to understand how social housing functioned. In the interview the head of development in a major public housing association was introduced to the project setting along with the project considerations that occurred to this.

The Farmer

The basis

- Born and raised in Råby
- Local contributor and former chairman for the local association
- Lives alone on the farm, with family placed on neighbouring farms
- Leading figure for the restoration of the village pond

Insight

- Observes an increasing tendendy of small farms, like his own, closing down

The Local association Chairman

The basis

- Born and raised in Råby
- Voluntary chairman of the local association
- Lives with her family in a city house

Insight

- Wishes for more indoor and outdoor spaces for the city's children
- The local hall lacks space
- Observes a growing tendency of newcomers to the city
- Finds it challenging to integrate newcomers into the community

The head of development

He presented the following highlights:

- To develop and improve a village size city, differ ent initiatives must occur
- Their base of interest in a new project always start with the municipality's interest in an area.
- The social housing association process a 3-room strategy for the projects, this is their ideal take on design for designing to a broader user group.
- Our project is interesting for the people already living withing Råby, who's living status changes and their need for new dwelling changes.
- Example: people getting divorce, people ages etc.
- A common house or similar should be for the city not just the residents
- This should ideally also be private founded in or der to have a cheaper cost.

Specific housing advice:

- 3-room housing strategy

Specific for social housing is the following relevant:

- The monthly rent is non-profit meaning that the overall rent is cheaper than private owned rents.
- The municipality must provide with 10% of the to tal building cost.
- 70% of users within the social housing associa tion is a 'single' living adult.
- By single meaning an elderly, singles and single parents living with or without children.

09 public housing

Randers municipality strive to generate a development of their small rural cities into becoming viable local societies. (Randers Kommune (2021, B). According to the results of the structure analysis of Råby a lack of varying housing opportunities, more specifically rental housing, limits a diverse residential possibility within Råby. To achieve a social sustainable development of Råby, it is important to implement such opportunities. Taking this into consideration together with the potential users it is chosen to establish public housing in the transformation of the farm.

Public housing offers in general housing for all types of residents. The focus is to allow high quality for a reasonable rental price, since they are run by non-profit housing organisations, they are built with public economic support, and the rent is based on the operation of the housing. (BL – Danmarks Almene Boliger, n.d.).

The most used public housing type is the family housing. This type allows residents of all ages and civil status to rent. The most typical family housing type is 80 sqm with three rooms but can vary in size to satisfy different resident's needs. By implementing family housing will contribute residential opportunities for different kind of residents and enable a diverse population within Råby. (BL – Danmarks Almene Boliger, n.d.).

When designing public housing different regulations have to be taken into consideration. These are both the general regulations from the Danish Building Regulations (BR18), but also some of the paragraphs in the Public Housing Law (Retsinformation.dk, 2024):

§ 5 b. Public housing organisations shall establish housing for all types of residents within a reasonable rent and letting the resident have influence on housing conditions.

§ 6. Public housing organisations shall establish, rent out, administrate, maintain and modernise the public housing, together with their common functions, such as laundry area, trash area, urbans facilities, etc.

§ 6 b. Public housing organisations shall ensure that the public housing are economically and socially efficient and are physically in good and up-to-date standard

§ 108. The housing interior must satisfy the residents reasonable needs. The housing must not have a luxurious character.

Stk. 3. Public housing must include toilet, bath and kitchen, if it is not a collective co-housing.

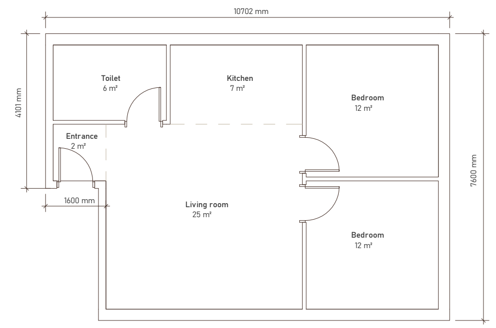
To ensure the possibility of elderly residents the following elder-friendly principles will be included in some of the housing units in the transformation.

The entrance of the housing units must allow easy access.

Must include housing units of one level ensuring no use for staircases.

10 Fictive plans

Apartment data



Reference adress: Steen Blichers gade 31, 8900 Randers.

Appartment - Randers

Building plot:	**747 m²**
Building:	**1380 m²**
Built:	1935 year
Renovated:	1987 year
Facade:	Red brick
Roof:	Red tile
Appartment:	**67 m²**
Plot ratio:	**185 %**

Heating and energy:

Heating:	District heating

Energy requirement:

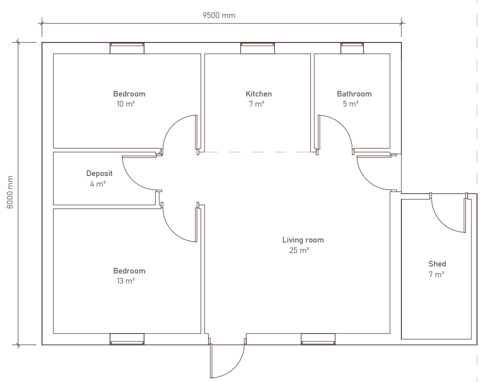
1930-:	141,35 kWh/m² per year
1979-:	110,25 kWh/m² per year

Properties unit		
Outerwalls	37,6	m2
Window/doors	8	m2
terrain/floor	86,25	m2
Roof	64,75	m2

Heatlosss					
Bygningsdel	**Areal m2**	**U-værdi (krav) W/m2K**	**Konstant for temperatur (gradtimer)**	**Varmetab kW/h / år**	
Tag	64,75	0,18	90	1048,95	
Ydervæg	37,6	0,175	90	592,2	
Terrændæk	86,25	0,09	62	481,275	
Vinduer og døre	8	1,15	90	828	
				2950,425	
			Varmebehov	44,03619	kW/h / m2 år

Typical user: The family

Town-house data



Reference adress: Toftevejen 21, 8970 Havndal.

Townhouse - Råby

Building plot: 267 m²
House: 75 m²
Built: 1989 year
Facade: Red brick
Roof: Red tile
Shed: 8 m²
Built: 1989 year
Facade: Red brick
Roof: Red tile
Plot ratio: 31 %

Heating and energy:
Heating: Electric heating
Heating agent: Electricity

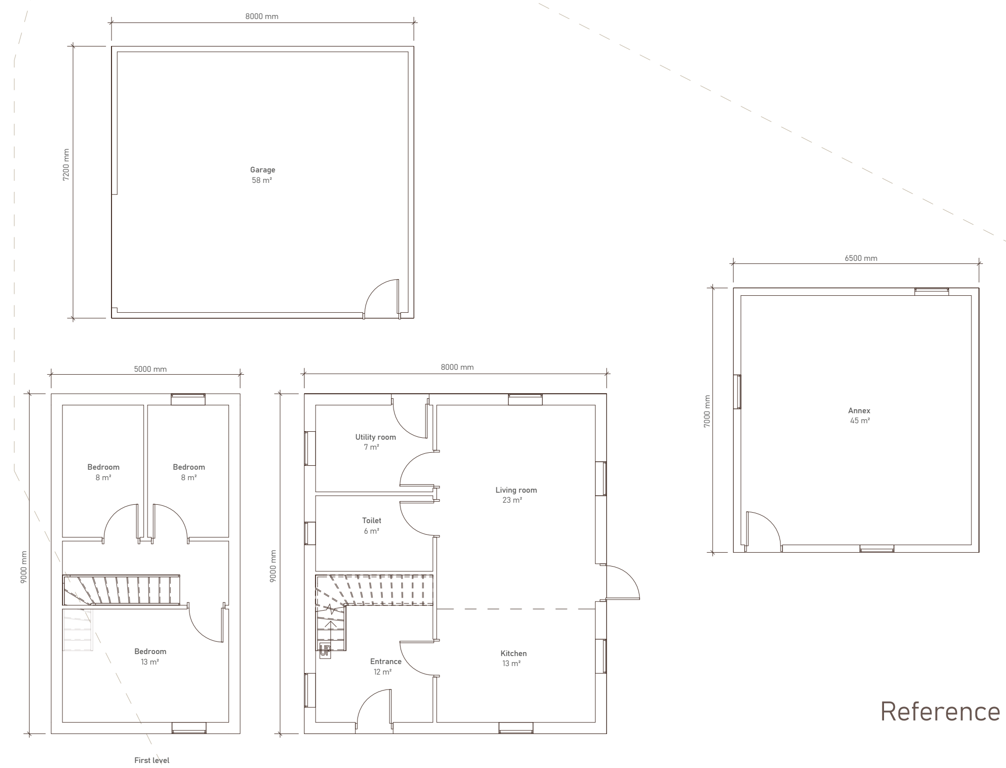
Energy requirement:
1979-: 99,058 kWh/m² per year

Propertie unit		
Outerwalls	93,4	m2
Window/doors	6,6	m2
terrain/floor	75	m2
Roof	82,4	m2

Heatloss					
Bygningsdel	Areal m2	U-værdi (krav) W/m2K	Konstant for temperatur (gradtimer)	Varmetab kW/h / år	
Tag	82,4	0,117	90	867,672	
Ydervæg	93,4	0,18	90	1513,08	
Terrændæk	75	0,09	62	418,5	
Vinduer og døre	6,6	1,15	90	683,1	
				3482,352	
			Varmebehov	46,43136	kW/h / m2 år

Typical user: The single

Single-family house data



Single-family house - Råby

Building plot: 712 m²
House: 120 m²
Built: 1936 year
Renovated: 1981 year
Facade: Red brick
Roof: Fiber cement
Annex: 45 m²
Built: 1936 year
Facade: Red brick
Roof: Fiber cement
Garage: 58 m²
Built: 2005 year
Facade: Red wood
Roof: Metal
Plot ratio: 31 %

Heating and energy:
Heating: Central heating with one firing unit
Heating agent: Fluid fuel
Supp. heating: Electric heating

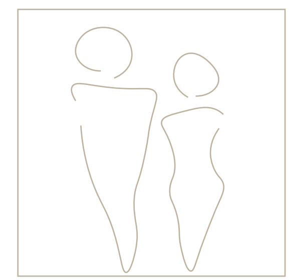
Energy requirement:
1930-: 141,82 kWh/m² per year
1979-: 102,58 kWh/m² per year

Reference adress: Grejsvang 6, 8970 Havndal.

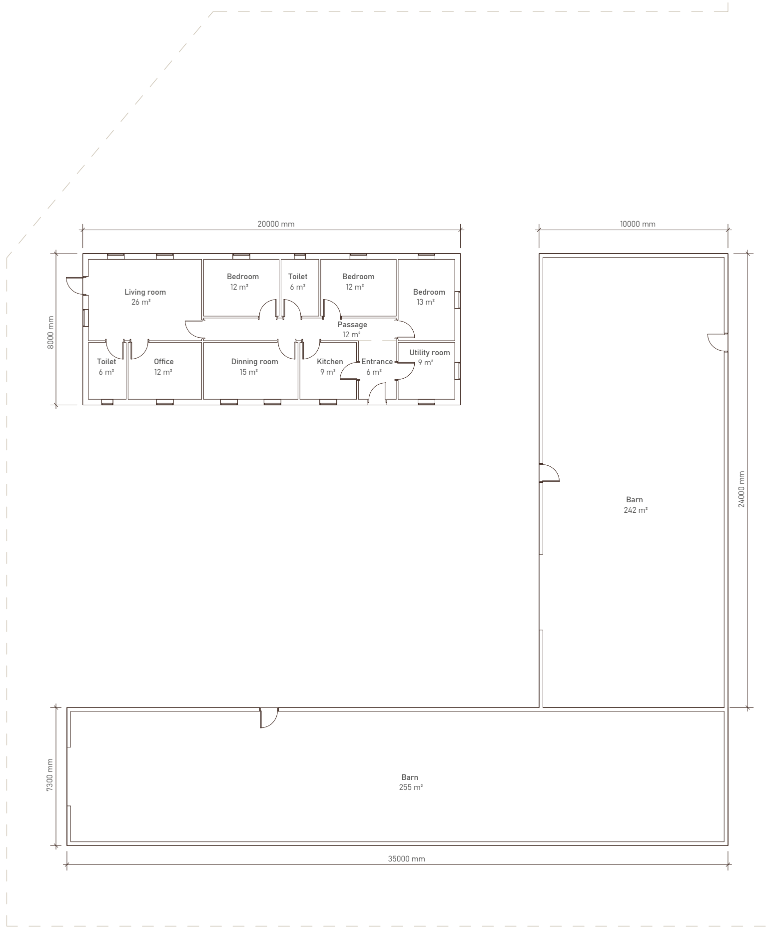
Properties unit		
Outerwalls	137	m2
Window/doors	15	m2
terrain/floor	72	m2
Roof	90,2	m2

Heatloss					
Bygningsdel	Areal m2	U-værdi (krav) W/m2K	Konstant for temperatur (gradtimer)	Varmetab kW/h / år	
Tag	90,2	0,117	90	949,806	
Ydervæg	137	0,175	90	2157,75	
Terrændæk	72	0,09	62	401,76	
Vinduer og døre	15	1,15	90	1552,5	
				5061,816	
			Varmebehov	42,1818	kW/h / m2 år

Typical user: The pair



Farmhouse data



Reference adress: Ved dammen 3, 8970 Havndal.

Farm house – Råby

Building plot: 8201 m²
House: 160 m²
Built: 1922 year
Facade: Red brick
Roof: Concrete tiles
Barn: 242 m²
Built: 1983 year
Facade: Red brick
Roof: Fiber cement
Barn: 255 m²
Built: 1878 year
Renovated: 1935 year
Facade: Red wood
Roof: Fiber cement
Barn: 261 m²
Built: 1973 year
Renovated: 1989 year
Facade: Red wood
Roof: Fiber cement
Plot ratio: 11 %

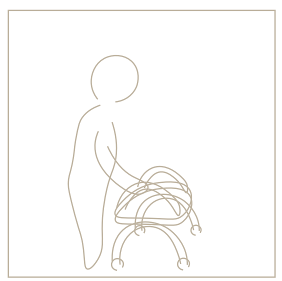
Heating and energy:
Heating: Central heating with one firing unit
Heating agent: Fluid fuel

Energy requirement:
1890-: 134,67 kWh/m² per year

Properties unit		
Outerwalls	118,72	m2
Window/d	21,6	m2
terrain/floo	180	m2
Roof	178,8	m2

Heatlosss					
Bygningsd	Areal	U-værdi (krav)	Konstant for temperatur (gradtimer)	Varmetab	
	m2	W/m2K		kW/h / år	
Tag	178,8	0,18	90	2896,56	
Ydervæg	118,72	0,175	90	1869,84	
Terrændæ	180	0,09	62	1004,4	
Vinduer og	21,6	1,15	90	2235,6	
				8006,4	
			Varmebehov	50,04	kW/h / m2 år

Typical user: The elderly



11 LCA fictive plans

LCA building rotation – Apartment

Building part	Material	Area	Amount	GWP	Data
		m2	Amount / m2	kg CO2-eq / m2	Source
Roof - utilised attic	Mineral wool (partition walls insulation)	64,75	0,11 m3	295,10	Generic data LCAbyg
	Damp insulation PE	64,75	0,2 kg	123,70	Generic data LCAbyg
	Mineral wool (partition walls insulation)	58,91	0,18 m3	427,20	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	5,83	0,02 m3	5,60	Generic data LCAbyg
	Cement screed	64,75	12 kg	154,30	Generic data LCAbyg
	Gypsum plaster board (perforated board)	64,75	1 m3	96,58	Generic data LCAbyg
	Application paint emulsion, dispersion paint	64,75	0,38 kg	52,20	Generic data LCAbyg
	Application primer emulsion, dispersion paint	64,75	0,19 kg	11,26	Generic data LCAbyg
			Total	1165,94	
Exterior wall	Damp insulation PE	37,6	0,2 kg	35,92	Generic data LCAbyg
	Mineral wool (blowable)	37,6	0,05 m3	248,00	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	3,4	0,24 m3	39,98	Generic data LCAbyg
	Mineral wool (partition walls insulation)	34,22	0,16 m3	219,70	Generic data LCAbyg
	Cement screed	37,6	12 kg	89,59	Generic data LCAbyg
	Gypsum plaster board (perforated board)	37,6	1 m3	56,08	Generic data LCAbyg
	Application paint emulsion, dispersion paint	37,6	0,38 kg	30,31	Generic data LCAbyg
	Application primer emulsion, dispersion paint	37,6	0,19 kg	6,54	Generic data LCAbyg
			Total	726,12	
Ground floor deck	Timber pine	26,24	0,02 m3	106,00	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	9,38	0,05 m3	22,51	Generic data LCAbyg
	Mineral wool (partition walls insulation)	84,42	0,05 m3	174,90	Generic data LCAbyg
	Underfloor heating system with insulation, PEX (200 mr	26,24	0,87 m3	483,50	Generic data LCAbyg
	Reinforced steel wire	86,25	4,03 kg	238,00	Generic data LCAbyg
	Ready-mixed concrete C20/25	86,25	0,1 m3	1958,00	Generic data LCAbyg
	Damp insulation PE	26,24	0,2 kg	25,07	Generic data LCAbyg
	EPS insulation for walls and roofs 035	26,24	0,3 m3	1060,00	Generic data LCAbyg
			Total	4067,98	
Windows	EPDM sealing for aluminium frame with 3-layer pane	8	5,78 m	78,90	Generic data LCAbyg
	Insulated glazing, triple pane (thickness: 0,036 m)	8	0,8 m2	784,60	Generic data LCAbyg
	Window fitting for double sash window	8	0,52 kg	35,84	Generic data LCAbyg
	Aluminium frame section, thermally separated, powder	8	0,83 m	109,10	Generic data LCAbyg
	Window frame (spruce)	8	2,87 m	84,20	Generic data LCAbyg
	Aluminium frame section, thermally separated, powder	8	0,86 m	121,50	Generic data LCAbyg
	Window sash (spruce)	8	2,76 m	85,88	Generic data LCAbyg
			Total	1300,02	Generic data LCAbyg

Appendix: LCA building rotation – Townhouse

Building part	Material	Area	Amount	GWP	Data
		m2	Amount / m2	kg CO2-eq / m2	
Roof - non utilised attic	Mineral wool (partition walls insulation)	75	0,32 m3	994,20	Generic data LCAbyg
	Damp insulation PE	82,4	0,2 kg	157,40	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	7,42	0,14 m3	49,86	Generic data LCAbyg
	Cement screed	82,4	12 kg	196,60	Generic data LCAbyg
	Gypsum plaster board (perforated board)	82,4	1 m3	123,10	Generic data LCAbyg
	Application paint emulsion, dispersion paint	82,4	0,38 kg	66,51	Generic data LCAbyg
	Application primer emulsion, dispersion paint	82,4	0,19 kg	14,34	Generic data LCAbyg
			Total	**1602,01**	
Exterior wall	Damp insulation PE	93,4	0,2 kg	178,50	Generic data LCAbyg
	Mineral wool (blowable)	93,4	0,13 m3	800,90	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	8,41	0,16 m3	62,57	Generic data LCAbyg
	Mineral wool (partition walls insulation)	85	0,055 m3	0,02	Generic data LCAbyg
	Cement screed	93,4	12 kg	222,50	Generic data LCAbyg
	Gypsum plaster board (perforated board)	93,4	1 m3	139,30	Generic data LCAbyg
	Application paint emulsion, dispersion paint	93,4	0,38 kg	75,30	Generic data LCAbyg
	Application primer emulsion, dispersion paint	93,4	0,19 kg	16,24	Generic data LCAbyg
			Total	**1495,33**	
Ground floor deck	Timber pine	75	0,02 m3	302,90	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	7,5	0,05 m3	18,00	Generic data LCAbyg
	Mineral wool (partition walls insulation)	67,5	0,05 m3	139,80	Generic data LCAbyg
	Underfloor heating system with insulation, PEX (200 mı	75	0,87 m3	1382,00	Generic data LCAbyg
	Reinforced steel wire	75	4,03 kg	207,00	Generic data LCAbyg
	Ready-mixed concrete C20/25	75	0,1 m3	1703,00	Generic data LCAbyg
	Damp insulation PE	75	0,2 kg	71,65	Generic data LCAbyg
	EPS insulation for walls and roofs 035	75	0,3 m3	3031,00	Generic data LCAbyg
			Total	**6855,35**	
Windows	EPDM sealing for aluminium frame with 3-layer pane	6,6	5,78 m	65,09	Generic data LCAbyg
	Insulated glazing, triple pane (thickness: 0,036 m)	6,6	0,8 m2	647,30	Generic data LCAbyg
	Window fitting for double sash window	6,6	0,52 kg	29,57	Generic data LCAbyg
	Aluminium frame section, thermally separated, powder	6,6	0,83 m	89,98	Generic data LCAbyg
	Window frame (spruce)	6,6	2,87 m	69,46	Generic data LCAbyg
	Aluminium frame section, thermally separated, powder	6,6	0,86 m	100,30	Generic data LCAbyg
	Window sash (spruce)	6,6	2,76 m	70,85	Generic data LCAbyg
			Total	**1072,55**	Generic data LCAbyg

Appendix: LCA building rotation – Single-family house

Building part	Material	Area	Amount	GWP	Data
		m2	Amount / m2	kg CO2-eq / m2	
Roof - non utilised attic	Mineral wool (partition walls insulation)	82,1	0,32 m3	1088,00	Generic data LCAbyg
	Damp insulation PE	90,2	0,2 kg	172,30	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	8,12	0,02 m3	74,05	Generic data LCAbyg
	Cement screed	90,2	12 kg	214,90	Generic data LCAbyg
	Gypsum plaster board (perforated board)	90,2	1 m3	134,50	Generic data LCAbyg
	Application paint emulsion, dispersion paint	90,2	0,38 kg	72,72	Generic data LCAbyg
	Application primer emulsion, dispersion paint	90,2	0,19 kg	15,68	Generic data LCAbyg
			Total	**1772,15**	
Exterior wall	Damp insulation PE	137	0,2 kg	261,80	Generic data LCAbyg
	Mineral wool (blowable)	137	0,05 m3	451,80	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	12,33	0,24 m3	145,00	Generic data LCAbyg
	Mineral wool (partition walls insulation)	124,7	0,16 m3	800,70	Generic data LCAbyg
	Cement screed	137	12 kg	326,40	Generic data LCAbyg
	Gypsum plaster board (perforated board)	137	1 m3	204,40	Generic data LCAbyg
	Application paint emulsion, dispersion paint	137	0,38 kg	109,70	Generic data LCAbyg
	Application primer emulsion, dispersion paint	137	0,19 kg	23,82	Generic data LCAbyg
			Total	**2323,62**	
Ground floor deck	Timber pine	72	0,02 m3	290,80	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	7,2	0,05 m3	17,28	Generic data LCAbyg
	Mineral wool (partition walls insulation)	64,8	0,05 m3	134,20	Generic data LCAbyg
	Underfloor heating system with insulation, PEX (200 mı	72	0,87 m3	1327,00	Generic data LCAbyg
	Reinforced steel wire	72	4,03 kg	198,70	Generic data LCAbyg
	Ready-mixed concrete C20/25	72	0,1 m3	1635,00	Generic data LCAbyg
	Damp insulation PE	72	0,2 kg	68,79	Generic data LCAbyg
	EPS insulation for walls and roofs 035	72	0,3 m3	2910,00	Generic data LCAbyg
			Total	**6581,77**	
Windows	EPDM sealing for aluminium frame with 3-layer pane	15	5,78 m	147,90	Generic data LCAbyg
	Insulated glazing, triple pane (thickness: 0,036 m)	15	0,8 m2	1471,00	Generic data LCAbyg
	Window fitting for double sash window	15	0,52 kg	67,20	Generic data LCAbyg
	Aluminium frame section, thermally separated, powder	15	0,83 m	204,50	Generic data LCAbyg
	Window frame (spruce)	15	2,87 m	157,90	Generic data LCAbyg
	Aluminium frame section, thermally separated, powder	15	0,86 m	227,90	Generic data LCAbyg
	Window sash (spruce)	15	2,76 m	161,00	Generic data LCAbyg
			Total	**2437,40**	Generic data LCAbyg

Appendix: LCA building rotation - Farmhouse

Building part	Material	Area	Amount	GWP	Data
		m2	Amount / m2	kg CO2-eq / m2	
Roof - non utilised attic	Mineral wool (partition walls insulation)	178,8	0,11 m3	814,80	Generic data LCAbyg
	Damp insulation PE	178,8	0,2 kg	341,60	Generic data LCAbyg
	Mineral wool (partition walls insulation)	162,71	0,18 m3	1180,00	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	16,4	0,02 m3	15,74	Generic data LCAbyg
	Cement screed	178,8	12 kg	426,00	Generic data LCAbyg
	Gypsum plaster board (perforated board)	178,8	1 m3	266,70	Generic data LCAbyg
	Application paint emulsion, dispersion paint	178,8	0,38 kg	144,10	Generic data LCAbyg
	Application primer emulsion, dispersion paint	178,8	0,19 kg	31,09	Generic data LCAbyg
			Total	3220,03	
Exterior wall	Damp insulation PE	118,72	0,2 kg	226,80	Generic data LCAbyg
	Mineral wool (blowable)	118,72	0,05 m3	391,50	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	10,7	0,24 m3	125,80	Generic data LCAbyg
	Mineral wool (partition walls insulation)	108,04	0,16 m3	693,70	Generic data LCAbyg
	Cement screed	118,72	12 kg	282,90	Generic data LCAbyg
	Gypsum plaster board (perforated board)	118,72	1 m3	177,10	Generic data LCAbyg
	Application paint emulsion, dispersion paint	118,72	0,38 kg	95,71	Generic data LCAbyg
	Application primer emulsion, dispersion paint	118,72	0,19 kg	20,64	Generic data LCAbyg
			Total	2014,15	
Ground floor deck	Timber pine	180	0,02 m3	726,90	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	18	0,05 m3	43,20	Generic data LCAbyg
	Mineral wool (partition walls insulation)	162	0,05 m3	335,60	Generic data LCAbyg
	Underfloor heating system with insulation, PEX (200 mı	180	0,87 m3	3317,00	Generic data LCAbyg
	Reinforced steel wire	180	4,03 kg	496,70	Generic data LCAbyg
	Ready-mixed concrete C20/25	180	0,1 m3	4087,00	Generic data LCAbyg
	Damp insulation PE	180	0,2 kg	172,00	Generic data LCAbyg
	EPS insulation for walls and roofs 035	180	0,3 m3	7274,00	Generic data LCAbyg
			Total	16452,40	
Windows	EPDM sealing for aluminium frame with 3-layer pane	21,6	5,78 m	213,00	Generic data LCAbyg
	Insulated glazing, triple pane (thickness: 0,036 m)	21,6	0,8 m2	2118,00	Generic data LCAbyg
	Window fitting for double sash window	21,6	0,52 kg	96,76	Generic data LCAbyg
	Aluminium frame section, thermally separated, powder	21,6	0,83 m	294,50	Generic data LCAbyg
	Window frame (spruce)	21,6	2,87 m	227,30	Generic data LCAbyg
	Aluminium frame section, thermally separated, powder	21,6	0,86 m	328,10	Generic data LCAbyg
	Window sash (spruce)	21,6	2,76 m	231,90	Generic data LCAbyg
			Total	3509,56	Generic data LCAbyg

12 calculations for rotations

Apartment

restart
with(*Gym*) :

Before renovation

$Year := ([2025, 2026, 2027, 2028, 2029, 2030, 2031, 2032, 2033, 2034, 2035, 2036, 2037, 2038, 2039, 2040, 2041, 2042, 2043, 2044, 2045, 2046, 2047, 2048, 2049, 2050, 2051, 2052, 2053, 2054, 2055, 2056, 2057, 2058, 2059, 2060, 2061, 2062, 2063, 2064, 2065, 2066, 2067, 2068, 2069, 2070, 2071, 2072, 2073, 2074]) :$

$Energy_{Before} := 110.25 :$

$Emission_{District} := 0.0878 :$

$Energy_{Before_{Total}} := Energy_{Before} \cdot Emission_{District}$

$$Energy_{Before_{Total}} := 9.679950 \qquad \textbf{(1.1.1.1)}$$

$Points_{Energy_{Before}} := ([9.679950, 9.679950]) :$

After renovation

$Energy_{After} := 44 :$

$Emission_{District} := 0.0878 :$

$Emission_{Eletric} := 0.135 :$

$Energy_{After_{Total}} := Energy_{After} \cdot Emission_{District} + 1.9 \cdot Emission_{Eletric}$

$$Energy_{After_{Total}} := 4.1197 \qquad \textbf{(1.1.2.1)}$$

LCA results

$Change_1 := 1.1 :$
(25 gange)

$Change_2 := 1.22 :$
(15 gange)

$Change_3 := 1.34 :$
(9 gange)

$Change_4 := 2.17 :$
(1 gang)

$LCA_{results} := (Change_1, Change_1, Change_1, Change_1, Change_1, Change_1, Change_1, Change_1, Change_1,$
$Change_1, Change_1, Change_1, Change_1, Change_1, Change_1, Change_1, Change_1, Change_1, Change_1,$
$Change_1, Change_1, Change_1, Change_1, Change_1, Change_1, Change_2, Change_2, Change_2, Change_2,$
$Change_2, Change_2, Change_2, Change_2, Change_2, Change_2, Change_2, Change_2, Change_2, Change_2,$
$Change_2, Change_3, Change_3, Change_3, Change_3, Change_3, Change_3, Change_3, Change_3, Change_3,$
$Change_4)$

$LCA_{results} := 1.1, 1.1, 1.1, 1.1, 1.1, 1.1, 1.1, 1.1, 1.1, 1.1, 1.1, 1.1, 1.1, 1.1, 1.1, 1.1, 1.1, 1.1,$ **(1.1.2.2)**
$1.1, 1.1, 1.1, 1.1, 1.1, 1.1, 1.1, 1.22, 1.22, 1.22, 1.22, 1.22, 1.22, 1.22, 1.22, 1.22, 1.22,$
$1.22, 1.22, 1.22, 1.22, 1.22, 1.34, 1.34, 1.34, 1.34, 1.34, 1.34, 1.34, 1.34, 1.34, 2.17$

Total

$GWP_{total} := ([Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1$
$+ Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}},$
$Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1$
$+ Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}},$
$Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1$
$+ Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}},$
$Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1$
$+ Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}},$
$Change_2 + Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}}, Change_2$
$+ Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}},$
$Change_2 + Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}}, Change_2$

$+ Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}}, Change_3 + Energy_{After_{Total}}, Change_3 + Energy_{After_{Total}},$
$Change_3 + Energy_{After_{Total}}, Change_3 + Energy_{After_{Total}}, Change_3 + Energy_{After_{Total}}, Change_3$
$+ Energy_{After_{Total}}, Change_3 + Energy_{After_{Total}}, Change_3 + Energy_{After_{Total}}, Change_3 + Energy_{After_{Total}},$
$Change_4 + Energy_{After_{Total}}])$

$GWP_{total} := [5.2197, 5.2197, 5.2197, 5.2197, 5.2197, 5.2197, 5.2197, 5.2197, 5.2197, 5.2197,$ **(1.1.2.3)**
$5.2197, 5.2197, 5.2197, 5.2197, 5.2197, 5.2197, 5.2197, 5.2197, 5.2197, 5.2197, 5.2197,$
$5.2197, 5.2197, 5.2197, 5.2197, 5.3397, 5.3397, 5.3397, 5.3397, 5.3397, 5.3397, 5.3397,$
$5.3397, 5.3397, 5.3397, 5.3397, 5.3397, 5.3397, 5.3397, 5.3397, 5.4597, 5.4597, 5.4597,$
$5.4597, 5.4597, 5.4597, 5.4597, 5.4597, 5.4597, 6.2897]$

Yearly average

$GWP_{Total_{avaage}} := \frac{1}{50} \cdot ([5.2197 + 5.2197 + 5.2197 + 5.2197 + 5.2197 + 5.2197 + 5.2197 + 5.2197$
$+ 5.2197 + 5.2197 + 5.2197 + 5.2197 + 5.2197 + 5.2197 + 5.2197 + 5.2197 + 5.2197$
$+ 5.2197 + 5.2197 + 5.2197 + 5.2197 + 5.2197 + 5.2197 + 5.2197 + 5.2197 + 5.3397$
$+ 5.3397 + 5.3397 + 5.3397 + 5.3397 + 5.3397 + 5.3397 + 5.3397 + 5.3397 + 5.3397$
$+ 5.3397 + 5.3397 + 5.3397 + 5.3397 + 5.3397 + 5.4597 + 5.4597 + 5.4597 + 5.4597$
$+ 5.4597 + 5.4597 + 5.4597 + 5.4597 + 5.4597 + 6.2897])$

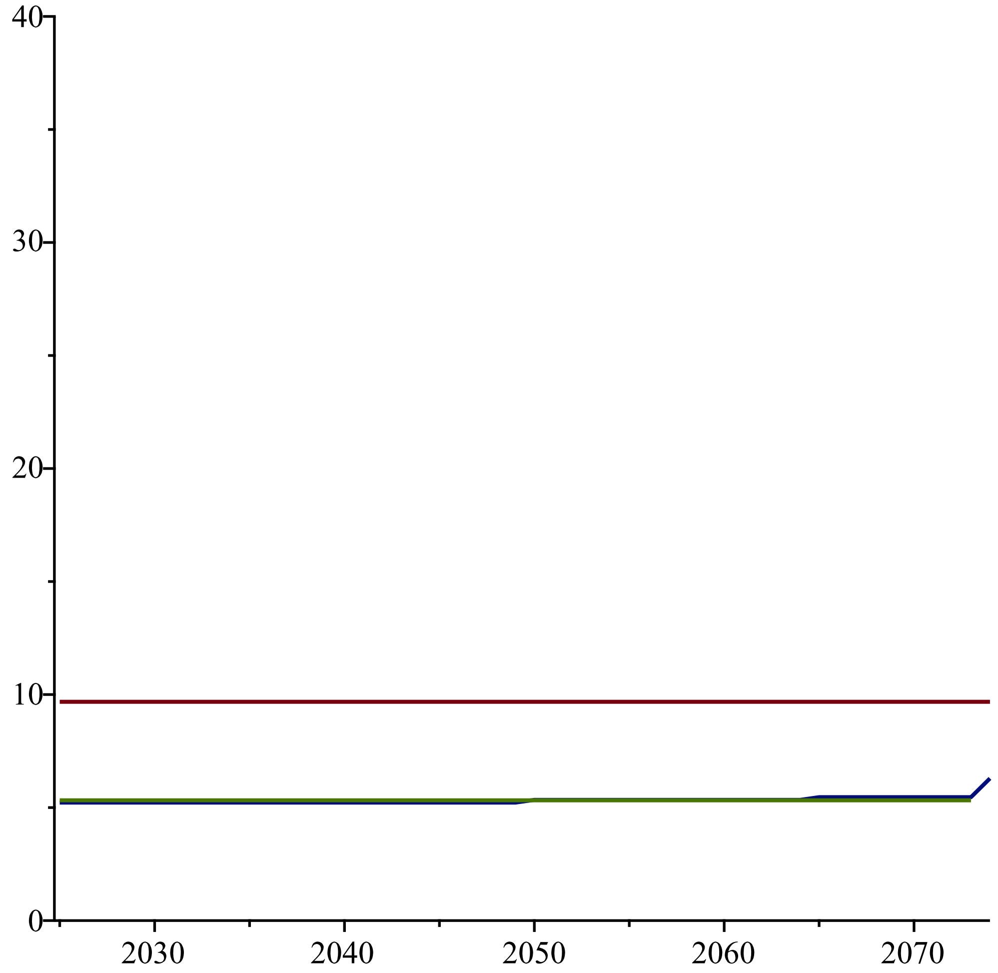
$$GWP_{Total_{avaage}} := [5.320300000] \qquad \textbf{(1.1.2.4)}$$

$Points_{average} := ([5.320300000, 5.320300000, 5.320300000, 5.320300000, 5.320300000,$
$5.320300000, 5.320300000, 5.320300000, 5.320300000, 5.320300000, 5.320300000, 5.320300000,$
$5.320300000, 5.320300000, 5.320300000, 5.320300000, 5.320300000, 5.320300000, 5.320300000,$
$5.320300000, 5.320300000, 5.320300000, 5.320300000, 5.320300000, 5.320300000, 5.320300000,$
$5.320300000, 5.320300000, 5.320300000, 5.320300000, 5.320300000, 5.320300000, 5.320300000,$
$5.320300000, 5.320300000, 5.320300000, 5.320300000, 5.320300000, 5.320300000, 5.320300000,$
$5.320300000, 5.320300000, 5.320300000, 5.320300000, 5.320300000, 5.320300000, 5.320300000,$
$5.320300000, 5.320300000,]) :$

Comparison

$p_1 := plot(Year, Points_{Energy_{Before}}) :$
$p_2 := plot(Year, GWP_{total}) :$
$p_3 := plot(Year, Points_{average}) :$

$with(plots) :$
$display(p_1, p_2, p_3)$



Townhouse

restart :
with(*Gym*) :

Before renovation

Year := ([2025, 2026, 2027, 2028, 2029, 2030, 2031, 2032, 2033, 2034, 2035, 2036, 2037, 2038, 2039, 2040, 2041, 2042, 2043, 2044, 2045, 2046, 2047, 2048, 2049, 2050, 2051, 2052, 2053, 2054, 2055, 2056, 2057, 2058, 2059, 2060, 2061, 2062, 2063, 2064, 2065, 2066, 2067, 2068, 2069, 2070, 2071, 2072, 2073, 2074]) :

$Energy_{Before} := 99.058$:

$Emission_{Electric} := 0.135$:

$Energy_{Before_{Total}} := Energy_{Before} \cdot Emission_{Electric}$

$$Energy_{Before_{Total}} := 13.372830 \quad \textbf{(1.2.1.1)}$$

$Points_{Energy_{Before}}$:= ([13.372830, 13.372830]) :

After renovation

Heatloss energy

$Energy_{After} := 46.43$:

$Emission_{Electric} := 0.135$:

$Emission_{District} := 0.0878$:

$Energy_{After_{Total}} := Energy_{After} \cdot Emission_{District} + Emission_{Electric} \cdot 1.9$

$$Energy_{After_{Total}} := 4.333054 \quad \textbf{(1.2.2.1)}$$

LCA results

$Change_1 := 1.02$:
(25 gange)

$Change_2 := 1.22$:
(15 gange)

$Change_3 := 1.47$:
(9 gange)

$Change_4 := 3, 6$:
(1 gang)

$LCA_{results}$:= ($Change_1$, $Change_2$, $Change_2$, $Change_2$, $Change_2$, $Change_2$, $Change_2$, $Change_2$, $Change_2$, $Change_2$, $Change_2$, $Change_2$, $Change_2$, $Change_2$, $Change_2$, $Change_2$, $Change_3$, $Change_3$, $Change_3$, $Change_3$, $Change_3$, $Change_3$, $Change_3$, $Change_3$, $Change_3$, $Change_4$)

$LCA_{results}$:= 1.02, 1.22, 1.22, 1.22, 1.22, 1.22, 1.22, 1.22, 1.22, 1.22, 1.22, 1.22, 1.22, 1.22, 1.22, 1.22, 1.47, 1.47, 1.47, 1.47, 1.47, 1.47, 1.47, 1.47, 1.47, 3, 6 **(1.2.2.2)**

Total

$$GWP_{total} := \Big(\big[Change_{1} + Energy_{After_{Total}}, Change_{1} + Energy_{After_{Total}}, Change_{1} + Energy_{After_{Total}}, Change_{1}$$
$$+ Energy_{After_{Total}}, Change_{1} + Energy_{After_{Total}}, Change_{1} + Energy_{After_{Total}}, Change_{1} + Energy_{After_{Total}},$$
$$Change_{1} + Energy_{After_{Total}}, Change_{1} + Energy_{After_{Total}}, Change_{1} + Energy_{After_{Total}}, Change_{1}$$
$$+ Energy_{After_{Total}}, Change_{1} + Energy_{After_{Total}}, Change_{1} + Energy_{After_{Total}}, Change_{1} + Energy_{After_{Total}},$$
$$Change_{1} + Energy_{After_{Total}}, Change_{1} + Energy_{After_{Total}}, Change_{1} + Energy_{After_{Total}}, Change_{1}$$
$$+ Energy_{After_{Total}}, Change_{1} + Energy_{After_{Total}}, Change_{1} + Energy_{After_{Total}}, Change_{1} + Energy_{After_{Total}},$$
$$Change_{1} + Energy_{After_{Total}}, Change_{1} + Energy_{After_{Total}}, Change_{1} + Energy_{After_{Total}}, Change_{1}$$
$$+ Energy_{After_{Total}}, Change_{2} + Energy_{After_{Total}}, Change_{2} + Energy_{After_{Total}}, Change_{2} + Energy_{After_{Total}},$$
$$Change_{2} + Energy_{After_{Total}}, Change_{2} + Energy_{After_{Total}}, Change_{2} + Energy_{After_{Total}}, Change_{2}$$
$$+ Energy_{After_{Total}}, Change_{2} + Energy_{After_{Total}}, Change_{2} + Energy_{After_{Total}}, Change_{2} + Energy_{After_{Total}},$$
$$Change_{2} + Energy_{After_{Total}}, Change_{2} + Energy_{After_{Total}}, Change_{2} + Energy_{After_{Total}}, Change_{2}$$
$$+ Energy_{After_{Total}}, Change_{2} + Energy_{After_{Total}}, Change_{3} + Energy_{After_{Total}}, Change_{3} + Energy_{After_{Total}},$$
$$Change_{3} + Energy_{After_{Total}}, Change_{3} + Energy_{After_{Total}}, Change_{3} + Energy_{After_{Total}}, Change_{3}$$
$$+ Energy_{After_{Total}}, Change_{3} + Energy_{After_{Total}}, Change_{3} + Energy_{After_{Total}}, Change_{3} + Energy_{After_{Total}},$$
$$Change_{4} + Energy_{After_{Total}}\big]\Big)$$

$$GWP_{total} := [5.353054, 5.353054, 5.353054, 5.353054, 5.353054, 5.353054, 5.353054,$$
$$5.353054, 5.353054, 5.353054, 5.353054, 5.353054, 5.353054, 5.353054, 5.353054,$$
$$5.353054, 5.353054, 5.353054, 5.353054, 5.353054, 5.353054, 5.353054, 5.353054,$$
$$5.353054, 5.353054, 5.553054, 5.553054, 5.553054, 5.553054, 5.553054, 5.553054,$$
$$5.553054, 5.553054, 5.553054, 5.553054, 5.553054, 5.553054, 5.553054, 5.553054,$$
$$5.553054, 5.803054, 5.803054, 5.803054, 5.803054, 5.803054, 5.803054, 5.803054,$$
$$5.803054, 5.803054, (3, 6) + 4.333054] \quad \textbf{(1.2.2.3)}$$

Yearly average

$$GWP_{Total_{avaage}} := \frac{1}{50} \cdot ([5.403054 + 5.403054 + 5.403054 + 5.403054 + 5.403054 + 5.403054$$
$$+ 5.403054 + 5.403054 + 5.403054 + 5.403054 + 5.403054 + 5.403054 + 5.403054$$
$$+ 5.403054 + 5.403054 + 5.403054 + 5.403054 + 5.403054 + 5.403054 + 5.403054$$
$$+ 5.403054 + 5.403054 + 5.403054 + 5.403054 + 5.403054 + 5.483054 + 5.483054$$
$$+ 5.483054 + 5.483054 + 5.483054 + 5.483054 + 5.483054 + 5.483054 + 5.483054$$
$$+ 5.483054 + 5.483054 + 5.483054 + 5.483054 + 5.483054 + 5.483054 + 5.713054$$
$$+ 5.713054 + 5.713054 + 5.713054 + 5.713054 + 5.713054 + 5.713054 + 5.713054$$
$$+ 5.713054 + 7.323054])$$

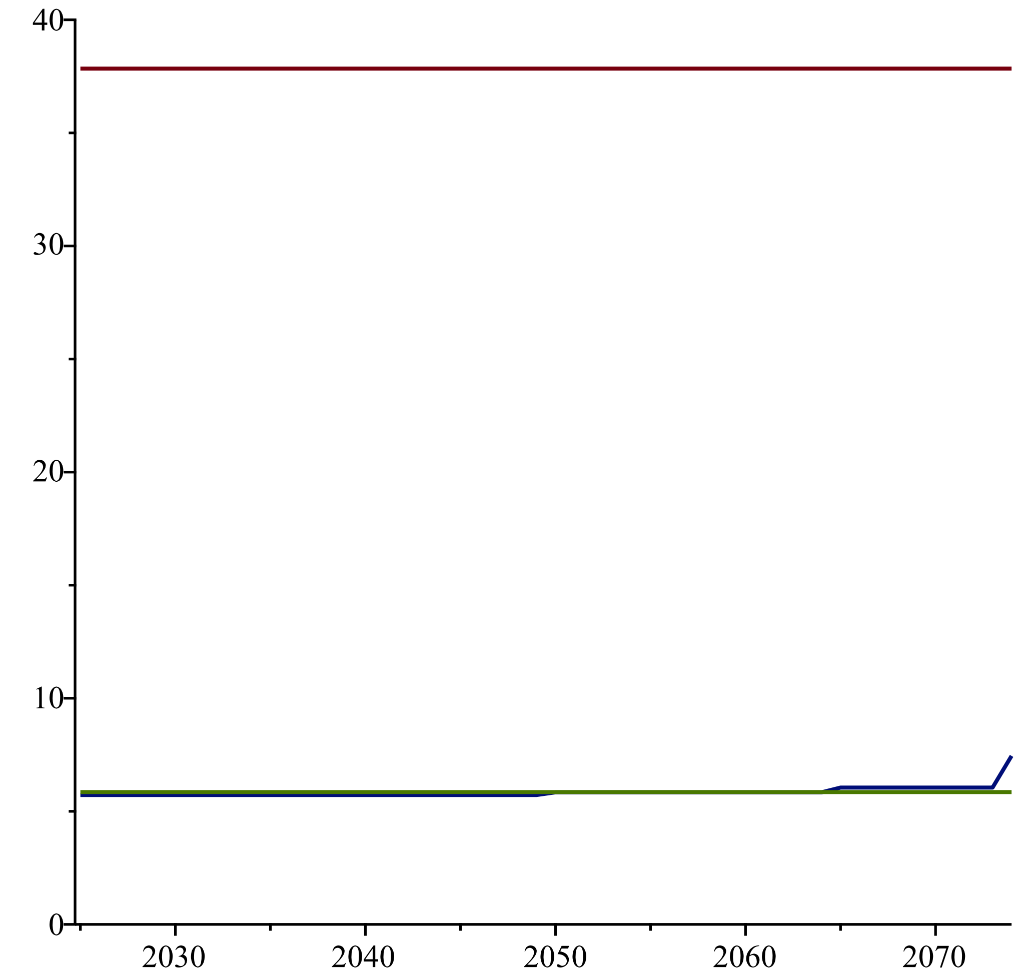
$$GWP_{Total_{avaage}} := [5.521254000] \quad \textbf{(1.2.2.4)}$$

$$Points_{average} := ([5.521254000, 5.521254000, 5.521254000, 5.521254000, 5.521254000, 5.521254000,$$
$$5.521254000, 5.521254000, 5.521254000, 5.521254000, 5.521254000, 5.521254000, 5.521254000,$$
$$5.521254000, 5.521254000, 5.521254000, 5.521254000, 5.521254000, 5.521254000, 5.521254000,$$
$$5.521254000, 5.521254000, 5.521254000, 5.521254000, 5.521254000, 5.521254000, 5.521254000,$$
$$5.521254000, 5.521254000, 5.521254000, 5.521254000, 5.521254000, 5.521254000, 5.521254000,$$
$$5.521254000, 5.521254000, 5.521254000, 5.521254000, 5.521254000, 5.521254000, 5.521254000,$$
$$5.521254000, 5.521254000, 5.521254000, 5.521254000, 5.521254000, 5.521254000, 5.521254000,$$
$$5.521254000, 5.521254000]) :$$

Comparison

$$p_1 := plot(Year, Points_{Energy_{Before}}) :$$
$$p_2 := plot(Year, GWP_{total}) :$$
$$p_3 := plot(Year, Points_{average}) :$$

$$with(plots) :$$
$$display(p_1, p_2, p_3)$$



Single family house

restart
with(*Gym*) :

Before renovation

$Year := ([2025, 2026, 2027, 2028, 2029, 2030, 2031, 2032, 2033, 2034, 2035, 2036, 2037, 2038, 2039, 2040, 2041, 2042, 2043, 2044, 2045, 2046, 2047, 2048, 2049, 2050, 2051, 2052, 2053, 2054, 2055, 2056, 2057, 2058, 2059, 2060, 2061, 2062, 2063, 2064, 2065, 2066, 2067, 2068, 2069, 2070, 2071, 2072, 2073, 2074]) :$

$Energy_{Before} := 102.58 :$

$Emission_{Fluidfuel} := 0.281 :$

$Energy_{Before_{Total}} := Energy_{Before} \cdot Emission_{Fluidfuel}$

$$Energy_{Before_{Total}} := 28.82498 \quad (1.3.1.1)$$

$Points_{Energy_{Before}} := ([28.82498, 28.82498]) :$

After renovation

$Energy_{After} := 42.18 :$

$Emission_{Electric} := 0.135 :$

$Emission_{District} := 0.0878 :$

$Energy_{After_{Total}} := Energy_{After} \cdot Emission_{District} + Emission_{Electric} \cdot 1.9$

$$Energy_{After_{Total}} := 3.959904 \quad (1.3.2.1)$$

LCA results

$Change_1 := 1.02 :$
(25 gange)

$Change_2 := 1.22 :$
(15 gange)

$Change_3 := 1.47 :$
(9 gange)

$Change_4 := 3.64 :$
(1 gang)

$GWP_{Total_{avaage}} := \frac{1}{50} \cdot (4.979904 + 5.179904 + 5.179904 + 5.179904 + 5.179904 + 5.179904 + 5.179904 + 5.179904 + 5.179904 + 5.179904 + 5.179904 + 5.179904 + 5.179904 + 5.179904 + 5.179904 + 5.179904 + 5.429904 + 5.429904 + 5.429904 + 5.429904 + 5.429904 + 5.429904 + 5.429904 + 5.429904 + 5.429904 + 7.599904)$

$$GWP_{Total_{avaage}} := 5.173304000 \quad (1.3.2.4)$$

$Points_{average} := ([5.173304000, 5.173304000]) :$

Comparison

$p_1 := plot(Year, Points_{Energy_{Before}}) :$

$p_2 := plot(Year, GWP_{total}) :$

$p_3 := plot(Year, Points_{average}) :$

with(*plots*) :
$display(p_1, p_2, p_3)$

$$37.84227, 37.84227]) :$$

After renovation

$Energy_{After} := 50.04$:
$Emission_{Electric} := 0.135$:
$Emission_{District} := 0.0878$:
$Energy_{After_{Total}} := Energy_{After} \cdot Emission_{District} + Emission_{Electric} \cdot 1.9$

$$Energy_{After_{Total}} := 4.650012 \qquad \textbf{(1.4.2.1)}$$

LCA results

$Change_1 := 1.07$:
(25 gange)

$Change_2 := 1.19$:
(15 gange)

$Change_3 := 1.4$:
(9 gange)

$Change_4 := 2.80$:
(1 gang)

$$LCA_{results} := (Change_1, Change_2, Change_2, Change_2, Change_2, Change_2, Change_2, Change_2, Change_2, Change_2, Change_2, Change_2, Change_2, Change_2, Change_2, Change_2, Change_3, Change_3, Change_3, Change_3, Change_3, Change_3, Change_3, Change_3, Change_3, Change_4)$$

$$LCA_{results} := 1.07, 1.19, 1.19, 1.19, 1.19, 1.19, 1.19, 1.19, 1.19, 1.19, 1.19, 1.19, 1.19, 1.19, 1.19, 1.19, 1.4, 1.4, 1.4, 1.4, 1.4, 1.4, 1.4, 1.4, 1.4, 2.80 \qquad \textbf{(1.4.2.2)}$$

Total

$$GWP_{total} := ([Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1$$

$$Change_3 + GWP_{operational}, Change_3 + GWP_{operational}, Change_3 + GWP_{operational}, Change_3 + GWP_{operational}, Change_4 + GWP_{operational}])$$

$$GWP_{embodied} := [2.072600000, 2.081600000, 2.081600000, 2.081600000, 2.081600000, 2.081600000, 2.081600000, 2.081600000, 2.081600000, 2.081600000, 2.081600000, 2.081600000, 2.081600000, 2.081600000, 2.081600000, 2.081600000, 3.667600000, 3.667600000, 3.667600000, 3.667600000, 3.667600000, 3.667600000, 3.667600000, 3.667600000, 3.667600000, 4.387600000] \qquad \textbf{(2.3)}$$

$$GWP_{embodied_{Average}} := \left(\frac{1}{50} \cdot [2.072600000 + 2.081600000 + 2.081600000 + 2.081600000 + 2.081600000 + 2.081600000 + 2.081600000 + 2.081600000 + 2.081600000 + 2.081600000 + 2.081600000 + 2.081600000 + 2.081600000 + 2.081600000 + 2.081600000 + 2.081600000 + 3.667600000 + 3.667600000 + 3.667600000 + 3.667600000 + 3.667600000 + 3.667600000 + 3.667600000 + 3.667600000 + 3.667600000 + 4.387600000]\right)$$

$$GWP_{embodied_{Average}} := [2.367068000] \qquad \textbf{(2.4)}$$

$$GWP_{average_{points}} := ([2.367068000, 2.367068000]) :$$

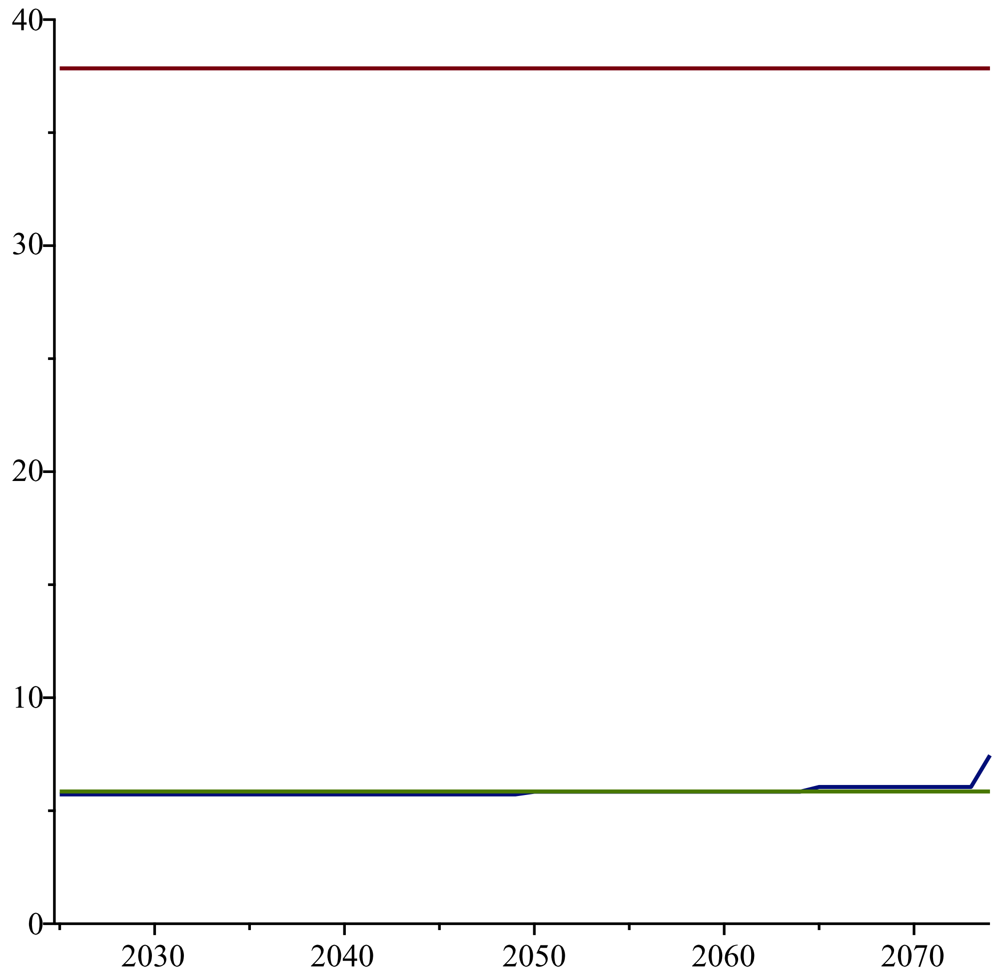
$with(plots)$:
$p_1 := plot(Year, GWP_{embodied})$:
$p_2 := plot(Year, GWP_{average_{points}})$:

$display(p_1, p_2)$

Comparison

$p_1 := plot(Year, Points_{Energy_{Before}})$:
$p_2 := plot(Year, GWP_{total})$:
$p_3 := plot(Year, Points_{average})$:

$with(plots)$:
$display(p_1, p_2, p_3)$



Landbo

$restart$
$with(Gym)$:

$Energy_{Be18} := 48$:

$LCA_{results} := (Change_1, Change_1, Change_1, Change_1, Change_1, Change_1, Change_1, Change_1, Change_1,$
$Change_1, Change_1, Change_1, Change_1, Change_1, Change_1, Change_1, Change_1, Change_1,$
$Change_1, Change_1, Change_1, Change_1, Change_1, Change_1, Change_2, Change_2, Change_2, Change_2,$
$Change_2, Change_2, Change_2, Change_2, Change_2, Change_2, Change_2, Change_2, Change_2, Change_2,$
$Change_2, Change_3, Change_3, Change_3, Change_3, Change_3, Change_3, Change_3, Change_3, Change_3,$
$Change_4)$

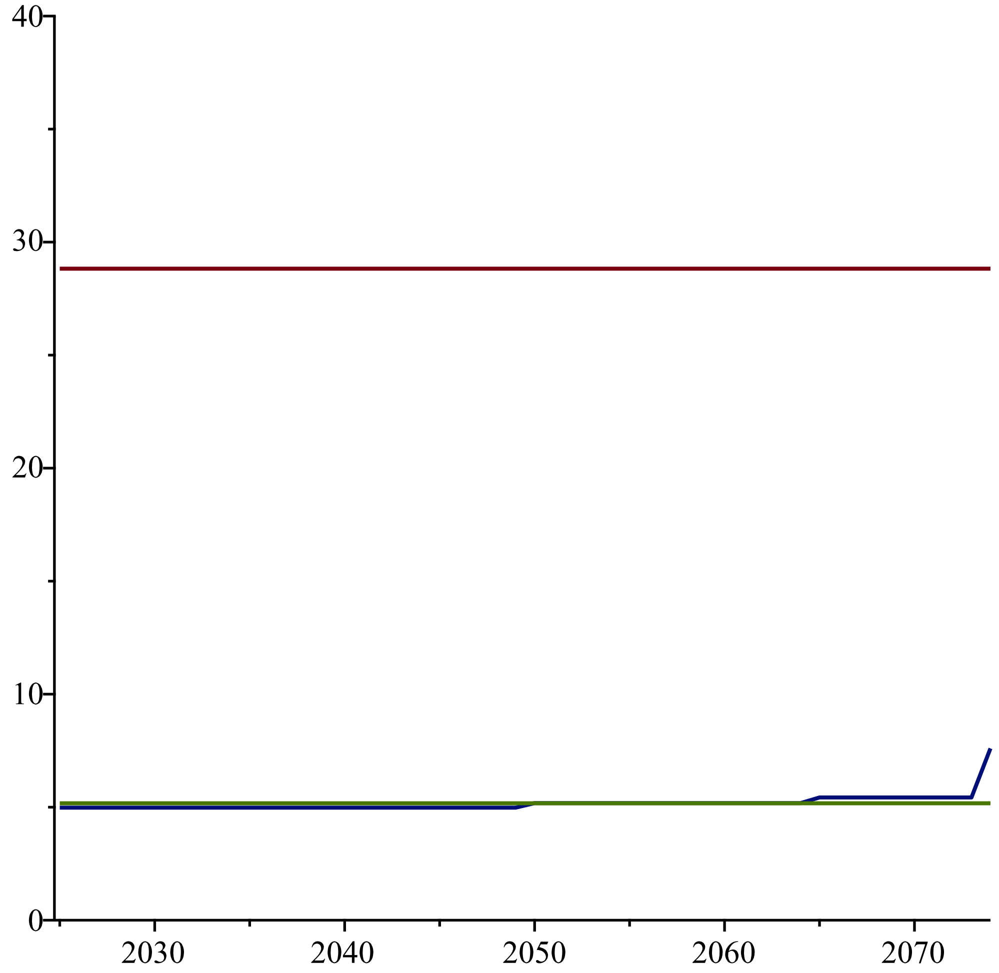
$LCA_{results} :=$ 1.02, 1.22, 1.22, 1.22, 1.22, 1.22, 1.22, 1.22, 1.22, 1.22, 1.22, 1.22, 1.22, 1.22, 1.22, 1.22, 1.47, 1.47, 1.47, 1.47, 1.47, 1.47, 1.47, 1.47, 1.47, 3.64 **(1.3.2.2)**

Total

$GWP_{total} := ([Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1$
$+ Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}},$
$Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1$
$+ Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}},$
$Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1$
$+ Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}},$
$Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1$
$+ Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}},$
$Change_2 + Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}}, Change_2$
$+ Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}},$
$Change_2 + Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}}, Change_2$
$+ Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}}, Change_3 + Energy_{After_{Total}}, Change_3 + Energy_{After_{Total}},$
$Change_3 + Energy_{After_{Total}}, Change_3 + Energy_{After_{Total}}, Change_3 + Energy_{After_{Total}}, Change_3$
$+ Energy_{After_{Total}}, Change_3 + Energy_{After_{Total}}, Change_3 + Energy_{After_{Total}}, Change_3 + Energy_{After_{Total}},$
$Change_4 + Energy_{After_{Total}}])$

$GWP_{total} :=$ [4.979904, 5.179904, 5.179904, 5.179904, 5.179904, 5.179904, 5.179904, 5.179904, 5.179904, 5.179904, 5.179904, 5.179904, 5.179904, 5.179904, 5.179904, 5.179904, 5.429904, 5.429904, 5.429904, 5.429904, 5.429904, 5.429904, 5.429904, 5.429904, 5.429904, 7.599904] **(1.3.2.3)**

$plot(Year, GWP_{total})$:



Farmhouse

restart
with(*Gym*) :

Before renovation

$Year := ([2025, 2026, 2027, 2028, 2029, 2030, 2031, 2032, 2033, 2034, 2035, 2036, 2037, 2038, 2039, 2040, 2041, 2042, 2043, 2044, 2045, 2046, 2047, 2048, 2049, 2050, 2051, 2052, 2053, 2054, 2055, 2056, 2057, 2058, 2059, 2060, 2061, 2062, 2063, 2064, 2065, 2066, 2067, 2068, 2069, 2070, 2071, 2072, 2073, 2074]) :$

$Energy_{Before} := 134.67 :$

$Emission_{Fluidfuel} := 0.281 :$

$Energy_{Before_{Total}} := Energy_{Before} \cdot Emission_{Fluidfuel}$

$$Energy_{Before_{Total}} := 37.84227 \quad \textbf{(1.4.1.1)}$$

$Points_{Energy_{Before}} := ([37.84227, 37.84227, 37.84227, 37.84227, 37.84227, 37.84227, 37.84227, 37.84227, 37.84227, 37.84227, 37.84227, 37.84227, 37.84227, 37.84227, 37.84227, 37.84227,$

$+ Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}},$
$Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1$
$+ Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}},$
$Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1 + Energy_{After_{Total}}, Change_1$
$+ Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}},$
$Change_2 + Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}}, Change_2$
$+ Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}},$
$Change_2 + Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}}, Change_2$
$+ Energy_{After_{Total}}, Change_2 + Energy_{After_{Total}}, Change_3 + Energy_{After_{Total}}, Change_3 + Energy_{After_{Total}},$
$Change_3 + Energy_{After_{Total}}, Change_3 + Energy_{After_{Total}}, Change_3 + Energy_{After_{Total}}, Change_3$
$+ Energy_{After_{Total}}, Change_3 + Energy_{After_{Total}}, Change_3 + Energy_{After_{Total}}, Change_3 + Energy_{After_{Total}},$
$Change_4 + Energy_{After_{Total}}])$

$GWP_{total} := [5.720012, 5.840012, 5.840012, 5.840012, 5.840012, 5.840012, 5.840012, 5.840012, 5.840012, 5.840012, 5.840012, 5.840012, 5.840012, 5.840012, 5.840012, 5.840012, 6.050012, 6.050012, 6.050012, 6.050012, 6.050012, 6.050012, 6.050012, 6.050012, 6.050012, 7.450012]$ **(1.4.2.3)**

$GWP_{Total_{avaage}} := \frac{1}{50} \cdot (5.720012 + 5.840012 + 5.840012 + 5.840012 + 5.840012 + 5.840012 + 5.840012 + 5.840012 + 5.840012 + 5.840012 + 5.840012 + 5.840012 + 5.840012 + 5.840012 + 5.840012 + 5.840012 + 6.050012 + 6.050012 + 6.050012 + 6.050012 + 6.050012 + 6.050012 + 6.050012 + 6.050012 + 6.050012 + 7.450012)$

$$GWP_{Total_{avaage}} := 5.850012000 \quad \textbf{(1.4.2.4)}$$

$Points_{average} := ([5.850012000, 5.850012000]) :$

$Emission_{district} := 0.0878 :$

$Emission_{sun} := 0.0146 :$

$$GWP_{operational} := \frac{Energy_{Be18}}{2} \cdot Emission_{district} + \frac{Energy_{Be18}}{2} \cdot Emission_{sun}$$

$$GWP_{operational} := 2.457600000 \qquad \mathbf{(2.1)}$$

$Year := ([2025, 2026, 2027, 2028, 2029, 2030, 2031, 2032, 2033, 2034, 2035, 2036, 2037, 2038, 2039, 2040, 2041, 2042, 2043, 2044, 2045, 2046, 2047, 2048, 2049, 2050, 2051, 2052, 2053, 2054, 2055, 2056, 2057, 2058, 2059, 2060, 2061, 2062, 2063, 2064, 2065, 2066, 2067, 2068, 2069, 2070, 2071, 2072, 2073, 2074]) :$

LCA

$Change_1 := -0.385 :$

$Change_2 := -0.376 :$

$Change_3 := 1.21 :$

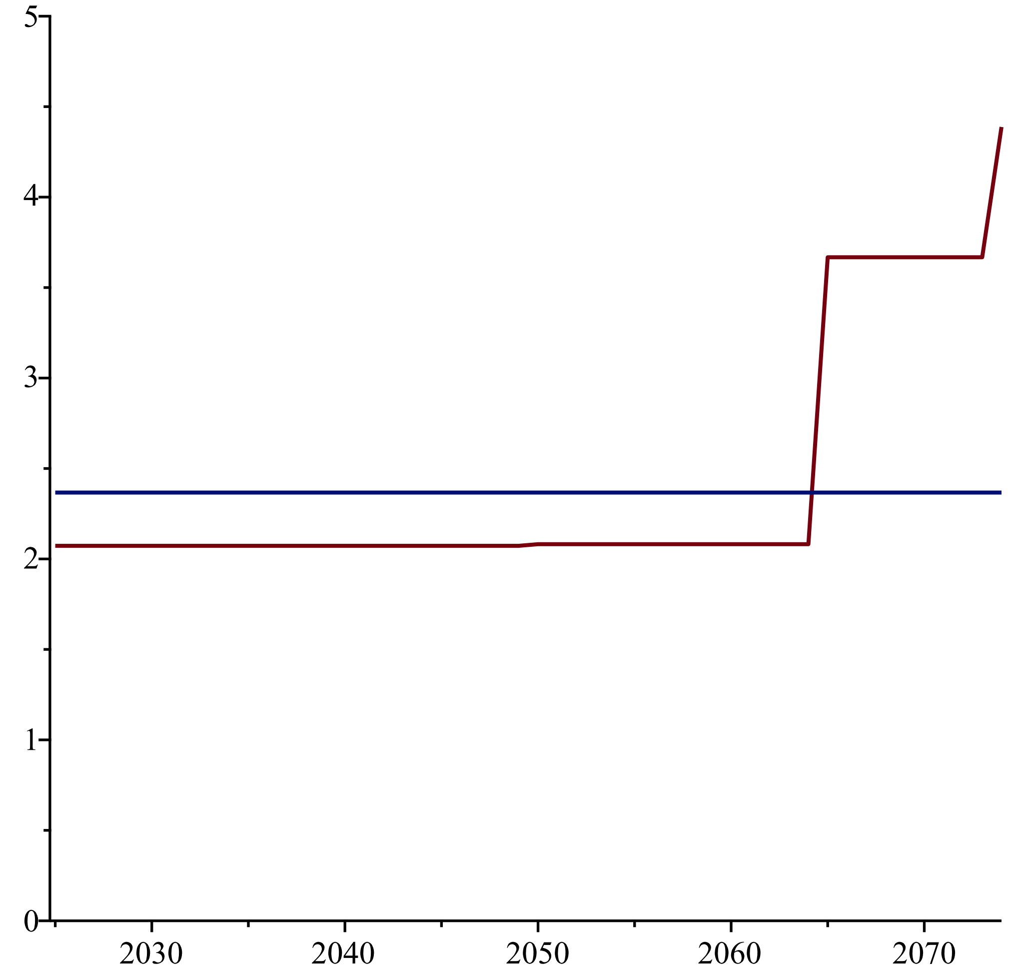
$Change_4 := 1.93 :$

$$LCA_{results} := (Change_1, Change_2, Change_2, Change_2, Change_2, Change_2, Change_2, Change_2, Change_2, Change_2, Change_2, Change_2, Change_2, Change_2, Change_2, Change_2, Change_3, Change_3, Change_3, Change_3, Change_3, Change_3, Change_3, Change_3, Change_3, Change_4)$$

$$LCA_{results} := -0.385, -0.376, -0.376, -0.376, -0.376, -0.376, -0.376, -0.376, -0.376, -0.376, -0.376, -0.376, -0.376, -0.376, -0.376, -0.376, 1.21, 1.21, 1.21, 1.21, 1.21, 1.21, 1.21, 1.21, 1.21, 1.93 \qquad \mathbf{(2.2)}$$

GWP total

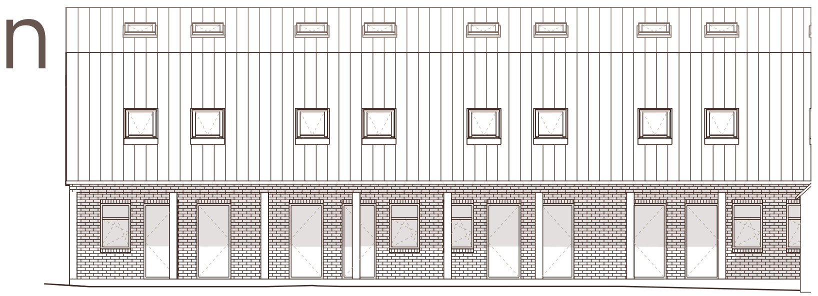
$$GWP_{embodied} := ([Change_1 + GWP_{operational}, Change_2 + GWP_{operational}, Change_2 + GWP_{operational}, Change_2 + GWP_{operational}, Change_2 + GWP_{operational}, Change_2 + GWP_{operational}, Change_2 + GWP_{operational}, Change_2 + GWP_{operational}, Change_2 + GWP_{operational}, Change_2 + GWP_{operational}, Change_2 + GWP_{operational}, Change_2 + GWP_{operational}, Change_2 + GWP_{operational}, Change_2 + GWP_{operational}, Change_2 + GWP_{operational}, Change_2 + GWP_{operational}, Change_3 + GWP_{operational}, Change_3 + GWP_{operational}, Change_3 + GWP_{operational}, Change_3 + GWP_{operational}, Change_3 + GWP_{operational},$$



13 Reference program

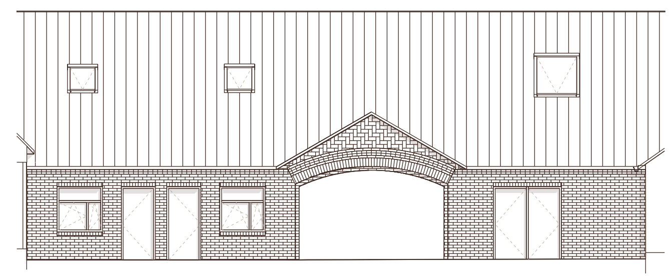
Unit	Users	Functions	Quantity	Size	Nat. light	Nat. vent.	Access to outside	min. m2	max. m2	
		Reference Program								
Unit		*Description*	-	*m2 (sqm)*	*yes/no*	*yes/no*	*yes/no*	*m2 (sqm)*	*m2 (sqm)*	
		St.Restrup 3/room dwelling	-	**83,5**				83,5	-	Gross area
	1 level	Kitchen	1	8 sqm	yes	-	yes	8		
		Living space	1	27,5 sqm	yes	-	yes	27,5		
		Bedroom	2	11,4 sqm	yes	-	yes	22,8		
		Toilet/bath	1	5,3 sqm	no	-	no	5,3		
		Entrance	1	6,2 sqm	yes	-	yes	6,2		
		Storage_in	1	2,7 sqm	no	-	no	2,7		
		Storage_out	1	2 sqm	no	-	yes	2		
							total	74,5	0	Net area

14 presentation elevations

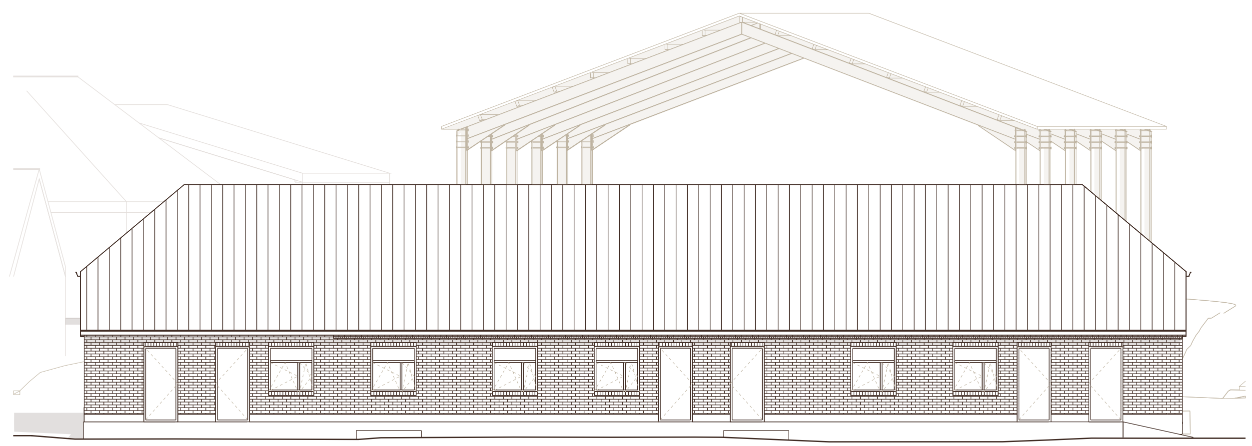


Elevation, east 1:200

Elevation, west 1:200



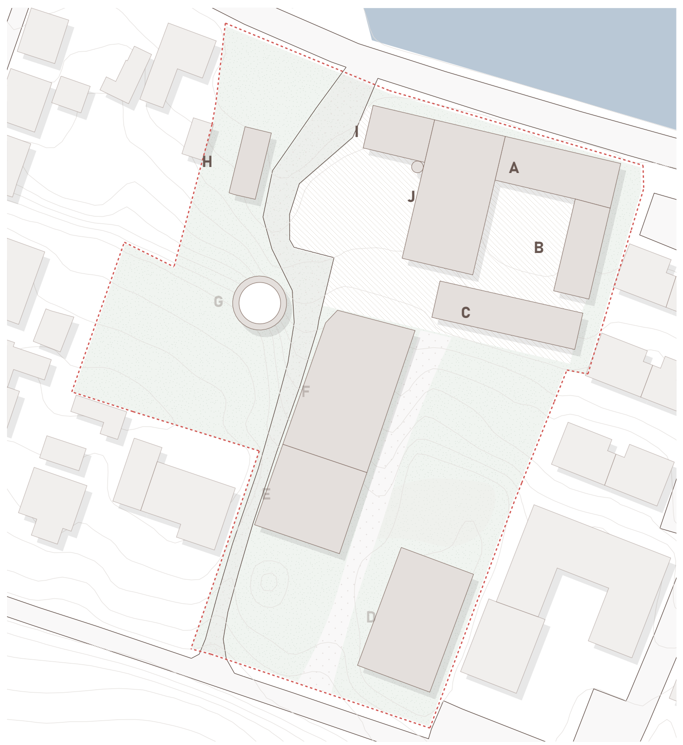
Elevation, south 1:200



Elevation, north 1:200

15 window amount

Building	Approx. sqm
Building A	5,5 m^2
Building B	1,8 m2
Building C	29,0 m2
Building H	9,6 m2
Building I	5,8 m2
Building J	17,8 m2
Total	**69,5 m2**

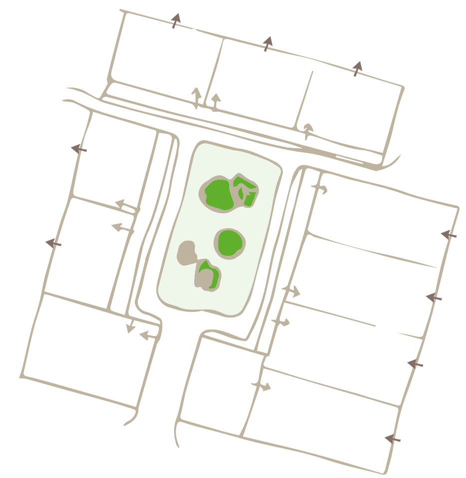


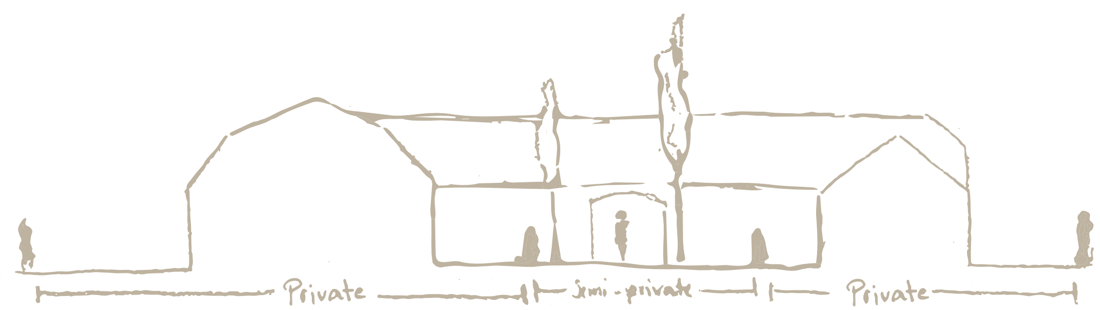
16 connections

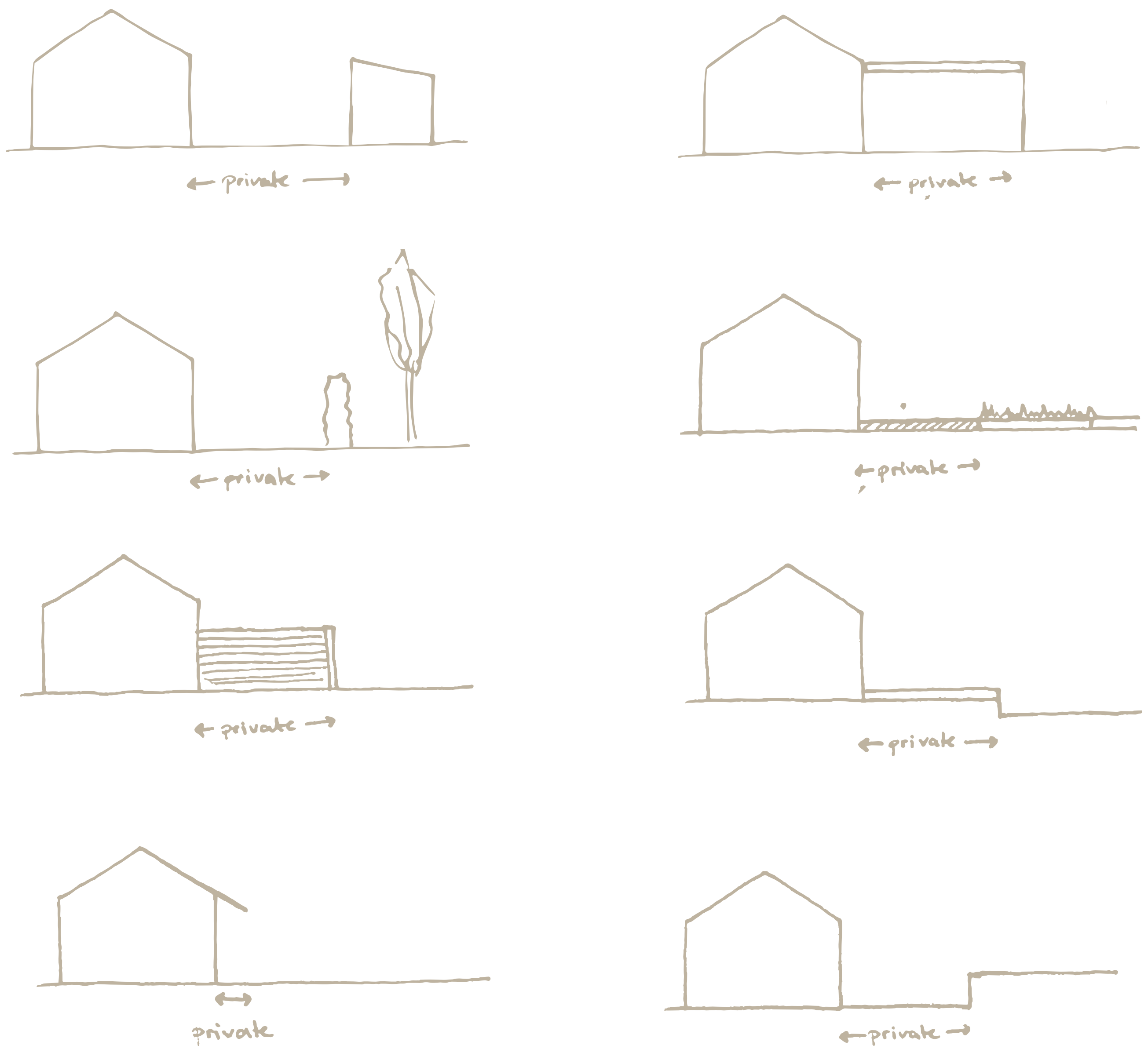
To divide the site into various zones and functions several strategies of making physical transitions are investigated. Eight different scenarios of spatial transition, that each provides either a different level of division or spatial experience.

Taking the wing farm into account, different strategies are necessary to incorporate to form a well-functioning circulation between private and public spaces. The intended transitions within and around the dwellings. Coming from a housing unit –the most private sphere – the boundary zone of the building forms an edge, whereas the space directly from this is potential a shared space between the residents of the site. In the courtyard between the housing units a semi-private space is located to create a shared common space for the residents. The transition from this area to the edge zone of building must be differentiated from each other in order to nudge the users' movements.

Around the buildings a path must be established for the users from the housing units to the parking area of easy access. The path must be differentiated from the building's edge by an overhang the extends the private sphere of the home. The semi-private space must consist of tall grass and other nature evocating elements. The private terrace gardens orientating away from the courtyard must be divided by hedges that separates these.







17 fire consideration

Since fire in buildings is a situation that can occur and should be handled and delayed in the best possible way to ensure time for residents to escape. Therefore, it is important to implement different fire considerations to ensure safety.

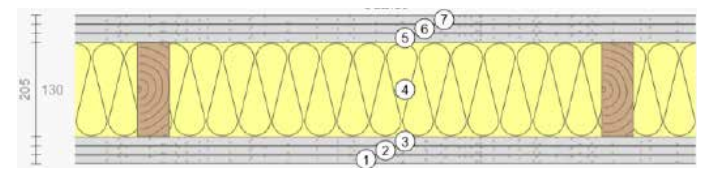
Fire partition

Parts of the design proposal consists of row-house dwelling within buildings with un-utilised roof attic, where a risk of fire spreading can appear. Therefore, the implementation of fire partition will be implemented in the design proposal. Here are the criteria that needs to be considered to achieve this. (Sode, T. R. & Jensen, L., 2024) (Clasen, G., 2023)

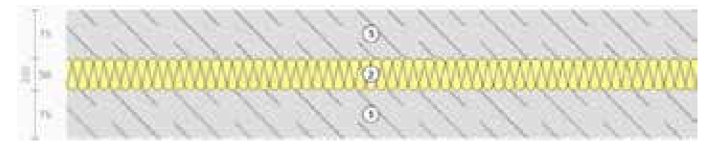
- Fire partition between each dwelling unit
- Fire partition is connected to the roof and exterior walls
- Fire partition can resist fire for 60 minutes
- Typical materials: Bricks, concrete, gypsum

To specify which material and wall construction to implement in the design proposal an examination of the three wall constructions will be executed based on LCA and depths. As it can be seen in the diagram the concrete construction has an incredible high global warming potential, which eliminates this construction. The re-used brick construction performs best according to having lowest global warming potential. But is also the widest wall construction, which is a disadvantage for the transformation due to the need of utilising as much floor space as possible. The gypsum construction has the second lowest global warming potential, almost as small as the bricks. This together with its narrow depth makes it the chosen one to implement in the design proposal.

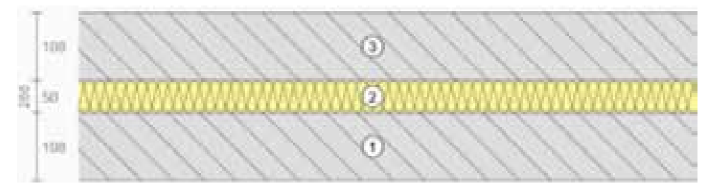
Gypsum

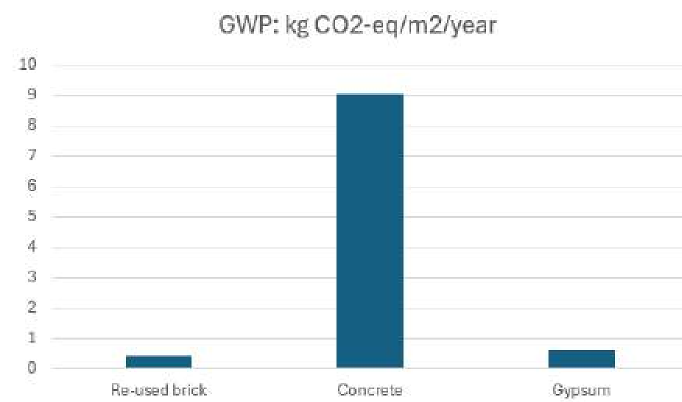


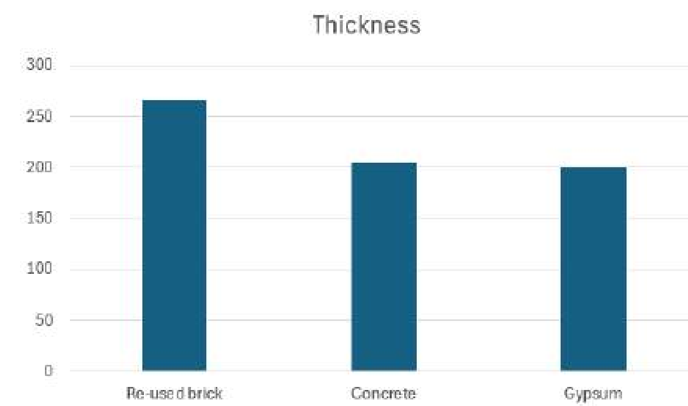
Concrete



Re-used bricks





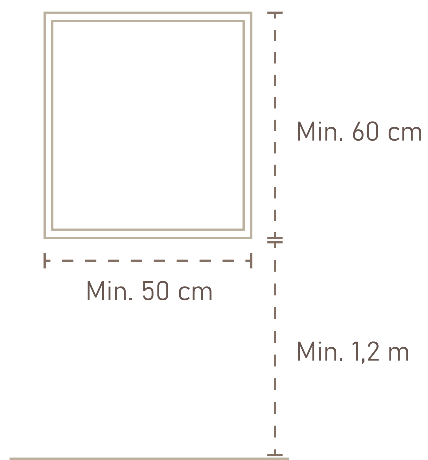


Building part	Material	Area	Amount	GWP	Data
		m2	Amount / m2	kg CO2-eq / m2	Source
Gypsum	Hemp insulation	0,91	0,13 m3	12,46	EPD Danmark (n.d. A)
	Cross laminated timber, CLT element, load-bearing	0,09	0,13 kg	0,94	Generic data LCAbyg
	Gypsum plaster board (fire protection) (thickness: 0,0125)	1	3 m2	5,07	Generic data LCAbyg
	Gypsum plaster board (fire protection) (thickness: 0,0125)	1	3 m2	5,07	Generic data LCAbyg
	Cement screed	1	12 kg	2,38	Generic data LCAbyg
	Application paint emulsion, dispersion paint	1	0,38 kg	0,81	Generic data LCAbyg
	Application primer emulsion, dispersion paint	1	0,19 kg	0,14	Generic data LCAbyg
	Cement screed	1	12 kg	2,38	Generic data LCAbyg
	Application paint emulsion, dispersion paint	1	0,38 kg	0,81	Generic data LCAbyg
	Application primer emulsion, dispersion paint	1	0,19 kg	0,14	Generic data LCAbyg
			Total	26,87	
Concrete	Hemp insulation	1	0,05 m3	5,27	EPD Danmark (n.d. A)
	Reinforcement steel wire	1	5 kg	3,42	Generic data LCAbyg
	Ready mixed concrete C30/37	1	0,75 m3	220,30	Generic data LCAbyg
	Reinforcement steel wire	1	5 kg	3,42	Generic data LCAbyg
	Ready mixed concrete C30/37	1	0,75 m3	220,30	Generic data LCAbyg
	Cement screed	1	12 kg	2,38	Generic data LCAbyg
	Application paint emulsion, dispersion paint	1	0,38 kg	0,81	Generic data LCAbyg
	Application primer emulsion, dispersion paint	1	0,19 kg	0,17	Generic data LCAbyg
	Cement screed	1	12 kg	2,38	Generic data LCAbyg
	Application paint emulsion, dispersion paint	1	0,38 kg	0,81	Generic data LCAbyg
	Application primer emulsion, dispersion paint	1	0,19 kg	0,17	Generic data LCAbyg
			Total	456,07	
Re-used bricks	Hemp insulation	1	0,05 m3	5,27	EPD Danmark (n.d. A)
	Re-used bricks	1	180 kg	4,20	EPD (Genbrugssten ApS, 2023)
	Lime plaster	1	11,9 kg	0,18	Generic data LCAbyg
	Lime gypsum interior plaster	1	18 kg	0,27	Generic data LCAbyg
	Re-used bricks	1	180 kg	4,20	Generic data LCAbyg
	Lime plaster	1	11,9 kg	0,18	Generic data LCAbyg
	Lime gypsum interior plaster	1	18 kg	0,27	Generic data LCAbyg
	Cement screed	1	12 kg	2,38	Generic data LCAbyg
	Application paint emulsion, dispersion paint	1	0,38 kg	0,81	Generic data LCAbyg
	Application primer emulsion, dispersion paint	1	0,19 kg	0,17	Generic data LCAbyg
	Cement screed	1	12 kg	2,38	Generic data LCAbyg
	Application paint emulsion, dispersion paint	1	0,38 kg	0,81	Generic data LCAbyg
	Application primer emulsion, dispersion paint	1	0,19 kg	0,17	Generic data LCAbyg
			Total	17,93	

Fire escape openings

Since one of the buildings consist of two storey dwellings units it is also important to look into rescue openings when designing windows openings. Here are the criteria that must be taken into consideration. (Sode, T.R., 2024)

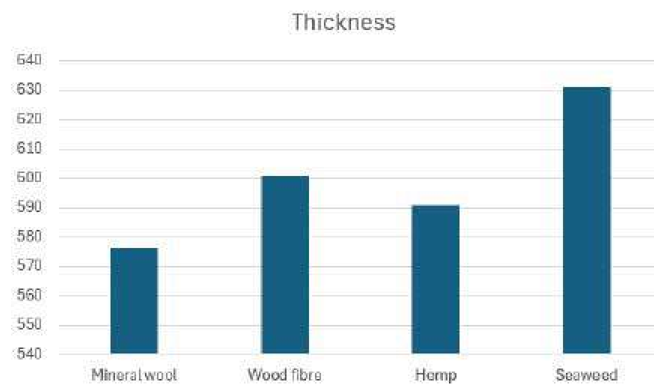
- Min. One rescue opening in each room
- The rescue opening must have a free height of min. 60 cm
- The rescue opening must have a free width of min. 50 cm
- The rescue opening must have a free height plus width of min. 150 cm
- The height from floor to bottom of the rescue opening must be max. 1,2 m

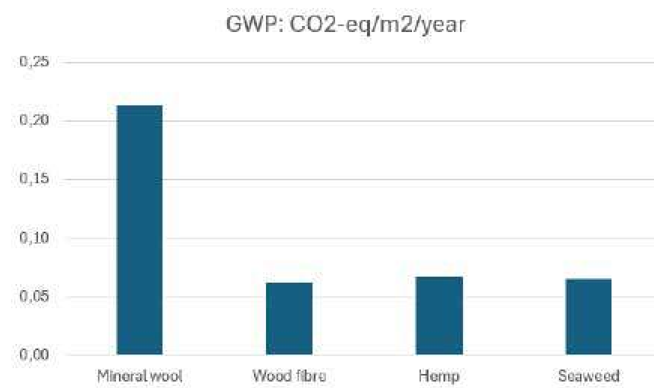


18 re-insulation

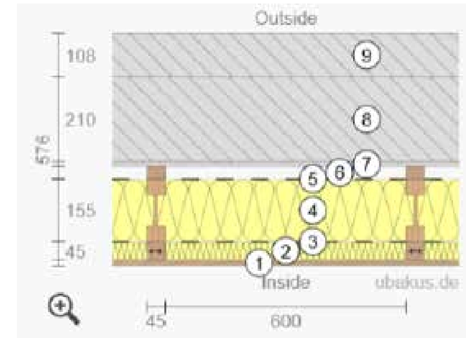
Examination of internal re-insulation materials with focus on building J as the base. In the LCA-analysis 1 sqm of wall is examined and the existing wall material will be excluded as this has already been build and are preserved in this case. The examination focus on implementing biobased materials and compare the results of the criteria below. Since hamp performs best allowing both a thin wall depth together with a low global warmng potential, this material i chosen as the insulation material for the re-insulation of the project.

- U-value: 0,18 W/m²K
- Low global warming potential
- Low wall thickness

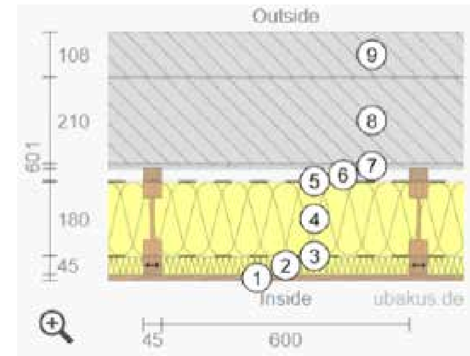




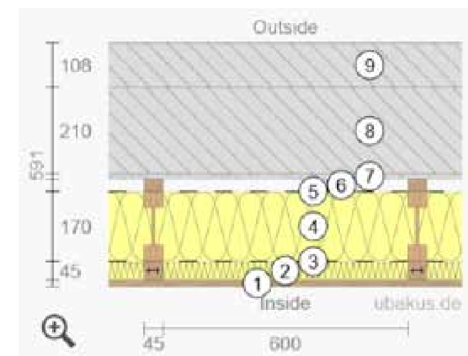
Mineral wool



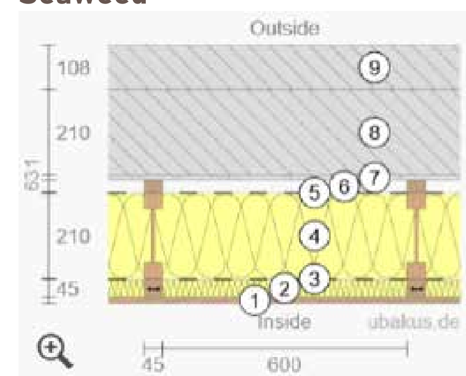
Wood fiber



Hemp



Seaweed



Building part	Material	Area	Amount	GWP	Data
		m2	Amount / m2	kg CO2-eq / m2	Source
Mineral wool	Mineral wool (partition walls insulation)	0,91	0,045 m3	1,70	Generic data LCAbyg
	Mineral wool (partition walls insulation)	0,98	0,065 m3	2,64	Generic data LCAbyg
	Mineral wool (partition walls insulation)	0,91	0,045 m3	1,70	Generic data LCAbyg
	Mineral wool (partition walls insulation)	0,91	0,045 m3	1,70	Generic data LCAbyg
	Damp insulation PE	1	0,005 kg	0,02	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	0,09	0,03 m3	0,13	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	0,09	0,045 m3	0,19	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	0,09	0,045 m3	0,19	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	0,02	0,012 m3	0,12	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	0,09	0,045 m3	0,19	Generic data LCAbyg
	Spruce plywood	1	0,02 m3	2,16	Generic data LCAbyg
	PE/PP fleece	1	0,005 kg	0,02	Generic data LCAbyg
			Total	10,76	
Wood fibre	Wood fibre insulation	0,91	0,045 m3	0,02	Generic data LCAbyg
	Wood fibre insulation	0,98	0,09 m3	0,05	Generic data LCAbyg
	Wood fibre insulation	0,91	0,045 m3	0,02	Generic data LCAbyg
	Wood fibre insulation	0,91	0,045 m3	0,02	Generic data LCAbyg
	Damp insulation PE	1	0,005 kg	0,02	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	0,09	0,03 m3	0,13	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	0,09	0,045 m3	0,19	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	0,09	0,045 m3	0,19	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	0,02	0,012 m3	0,12	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	0,09	0,045 m3	0,19	Generic data LCAbyg
	Spruce plywood	1	0,02 m3	2,16	Generic data LCAbyg
	PE/PP fleece	1	0,005 kg	0,02	Generic data LCAbyg
			Total	3,13	
Hemp	Hemp insulation	0,91	0,045 m3	0,08	EPD Danmark (n.d. A)
	Hemp insulation	0,98	0,08 m3	0,16	EPD Danmark (n.d. A)
	Hemp insulation	0,91	0,045 m3	0,08	EPD Danmark (n.d. A)
	Hemp insulation	0,91	0,045 m3	0,08	EPD Danmark (n.d. A)
	Damp insulation PE	1	0,005 kg	0,02	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	0,09	0,03 m3	0,13	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	0,09	0,045 m3	0,19	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	0,09	0,045 m3	0,19	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	0,02	0,012 m3	0,12	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	0,09	0,045 m3	0,19	Generic data LCAbyg
	Spruce plywood	1	0,02 m3	2,16	Generic data LCAbyg
	PE/PP fleece	1	0,005 kg	0,02	Generic data LCAbyg
			Total	3,42	
Seaweed	Seaweed insulation	0,91	0,045 m3	0,04	EPD Danmark (n.d. B)
	Seaweed insulation	0,98	0,12 m3	0,13	EPD Danmark (n.d. B)
	Seaweed insulation	0,91	0,045 m3	0,04	EPD Danmark (n.d. B)
	Seaweed insulation	0,91	0,045 m3	0,04	EPD Danmark (n.d. B)
	Damp insulation PE	1	0,005 kg	0,02	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	0,09	0,03 m3	0,13	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	0,09	0,045 m3	0,19	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	0,09	0,045 m3	0,19	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	0,02	0,012 m3	0,12	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	0,09	0,045 m3	0,19	Generic data LCAbyg
	Spruce plywood	1	0,02 m3	2,16	Generic data LCAbyg
	PE/PP fleece	1	0,005 kg	0,02	Generic data LCAbyg
			Total	3,27	

19 LCA - Landbo

Building part	Material	Area	Amount	GWP	Data
		m2	Amount / m2	kg CO2-eq / m2	Source
Roof - utilised attic	Hemp	522,1	0,225 m2	187,90	EPD Danmark (n.d. A)
	Hemp	475	0,09 m2	85,48	EPD Danmark (n.d. A)
	Hemp	516	0,11 m2	113,70	EPD Danmark (n.d. A)
	Construction wood, pine and spruce, wet and sawn	47	0,09 m2	203,00	EPD Danmark (n.d. A)
	Construction wood, pine and spruce, wet and sawn	5,2	0,11 m2	101,50	Generic data LCAbyg
	Damp insulation PE	522,1	0,002 kg	4,99	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	522,1	0,02 m2	501,20	Generic data LCAbyg
	Spruce plywood uncoated	522,1	0,02 m2	1504,00	Generic data LCAbyg
	Cement screed	522,1	12 kg	1244,00	Generic data LCAbyg
	Application paint emulsion, dispersion paint	522,1	0,38 kg	420,90	Generic data LCAbyg
	Application primer emulsion, dispersion paint	522,1	0,19 kg	90,77	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	494	0,0185 m3	438,70	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	494	0,0096 m3	228,80	Generic data LCAbyg
	Roof tile	494	1 m2	7993,00	Generic data LCAbyg
			Total	13117,94	
Exterior wall	Hemp	200,6	0,045 m2	18,05	EPD Danmark (n.d. A)
	Hemp	200,6	0,09 m2	36,10	EPD Danmark (n.d. A)
	Hemp	216	0,08 m2	34,55	EPD Danmark (n.d. A)
	Construction wood, pine and spruce, wet and sawn	47	0,09 m2	85,54	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	5,2	0,11 m2	25,34	Generic data LCAbyg
	Damp insulation PE	220,4	0,005 kg	5,26	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	19,8	0,075 m2	57,02	Generic data LCAbyg
	Spruce plywood uncoated	220,4	0,015 m2	476,10	Generic data LCAbyg
	Cement screed	220,4	12 kg	525,10	Generic data LCAbyg
	Application paint emulsion, dispersion paint	220,4	0,38 kg	177,70	Generic data LCAbyg
	Application primer emulsion, dispersion paint	220,4	0,19 kg	38,32	Generic data LCAbyg
	PE/PP fleece	220,4	0,19 kg	3,47	Generic data LCAbyg
			Total	1482,55	
Exterior floor decl	Hemp	37,2	0,425 m2	31,61	EPD Danmark (n.d. A)
	Construction wood, pine and spruce, wet and sawn	3,7	0,425 m2	75,48	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	40,9	0,03 m2	58,90	Generic data LCAbyg
	Damp insulation PE	40,9	0,002 m2	483,50	Generic data LCAbyg
	Timber larch	40,9	0,02 m2	457,00	Generic data LCAbyg
			Total	1106,49	
Ground floor deck	Timber Larch	366	0,02 m2	4089,00	Generic data LCAbyg
	Underfloor heating system with insulation, PEX (200 m	366	1 m2	777,00	Generic data LCAbyg
	Construction wood, pine and spruce, wet and sawn	32,94	0,045 m2	71,15	Generic data LCAbyg
	Chipboard	366	0,03 m2	4336,00	Generic data LCAbyg
	Damp insulation PE	366	0,002 m2	3,50	Generic data LCAbyg
	EPS insulation for walls and roofs 035	366	0,3 m3	14790,00	Generic data LCAbyg
			Total	24066,65	
Windows	EPDM sealing for aluminium frame with 3-layer pane	80,4	5,78 m	792,90	Generic data LCAbyg
	Insulated glazing, triple pane (thickness: 0,036 m)	80,4	0,8 m2	3943,00	Generic data LCAbyg
	Window fitting for double sash window	80,4	0,52 kg	360,20	Generic data LCAbyg
	Window frame (spruce)	80,4	2,87 m	846,20	Generic data LCAbyg
	Window sash (spruce)	80,4	2,76 m	863,10	Generic data LCAbyg
			Total	6805,40	
Sola r pane ls	Photovoltaic system 1000 kWh/m2*a (no electricity re	50	1 m2	30880,00	Generic data LCAbyg
			Total	30880,00	