

# Applied Research Report

## Structuring Roof Variation for Scalable Prefab Roof Renovation

---

Development and application of a morphological roof overview within the MEER / DÂK programme

|                           |                                                                       |
|---------------------------|-----------------------------------------------------------------------|
| <b>Author</b>             | Jorden Adolfse                                                        |
| <b>Company supervisor</b> | Rogier Lateveer                                                       |
| <b>Teacher supervisor</b> | Bauke Steenhuisen                                                     |
| <b>Student number</b>     | 1840473                                                               |
| <b>Programme</b>          | Master Next Level Engineering                                         |
| <b>Institution</b>        | Hogeschool Utrecht,<br>Research group Applied urban energy Transition |
| <b>Project context</b>    | MEER / DÂK - Building Balance                                         |
| <b>Date</b>               | 09 Juli 2026                                                          |
| <b>Version</b>            | 2.0                                                                   |

From variation in existing roofs to scalable prefab renovation

# Foreword

This graduation project was proposed by Rogier Lateveer, who asked me to look at the upscaling process of prefab roof renovation from a product-oriented perspective. At the start of the project, the building industry was a completely new field for me. I had to learn many new terms, processes and ways of working. However, this also gave me the opportunity to look at renovation from a fresh perspective. Instead of approaching the topic from a traditional architectural or construction background, I was able to analyse the renovation process through the lens of product design, standardisation and scalability.

My background is in product design, with a specialisation in interaction design. I completed my bachelor's degree in Amsterdam in 2024, and I am currently following the Master Next Level Engineering at Hogeschool Utrecht, with a focus on systems engineering and data science.



During the project, I mainly worked at Hogeschool Utrecht in the Built Environment Lab. This is also where the research group Nieuwe Energie in de Stad is partly located and where several students work on projects related to Building Balance. Being present in this environment helped me better understand the context of the building industry and the practical challenges connected to prefab renovation.

The project resulted in three professional products. The main professional product is the Morphological Roof Overview, which provides a structured way to analyse roof variation and translate it into useful information for prefab roof renovation. The second product is the advice report, which explains how the Morphological Roof Overview can be used and translates the results from the MEER project into practical recommendations. The third product is the applied research report. This report mainly provides the scientific underpinning of the research, but also explains in more depth how the Morphological Roof Overview was developed, how it should be used, how it was applied within the MEER project, and what future developments and recommendations follow from this.

My company supervisor, Rogier Lateveer, has worked for more than 20 years within this research group and originally has a background in architecture. His experience helped me understand building-related terminology and renovation processes whenever they were unfamiliar to me. The combination of his architectural knowledge and my product design background proved to be valuable throughout the project.

I hope you enjoy reading this report.

Jorden Adolfse

E: [Jorden.s.adolfse@gmail.com](mailto:Jorden.s.adolfse@gmail.com)

T: 0644205013

# Contents

|                                                                      |    |
|----------------------------------------------------------------------|----|
| Foreword.....                                                        | 2  |
| Executive Summary .....                                              | 5  |
| 1 Introduction .....                                                 | 6  |
| 1.1 Project background .....                                         | 6  |
| 1.2 Renovation challenge .....                                       | 6  |
| 1.3 Problem: custom roof renovation versus scalable prefab .....     | 6  |
| 1.4 Building Balance / DÂK 1.0 as first standard direction .....     | 7  |
| 1.5 Research aim and relevance .....                                 | 8  |
| 1.6 Intended audience and professional products .....                | 8  |
| 1.7 Research question, sub-questions and scope .....                 | 8  |
| 2 Research context and theoretical background .....                  | 9  |
| 2.1 MEER / DÂK project context .....                                 | 9  |
| 2.2 Prefab biobased roof renovation .....                            | 10 |
| 2.3 Roof variety analysis .....                                      | 10 |
| 2.4 Morphological analysis .....                                     | 12 |
| 2.5 Alternative methods for roof classification .....                | 12 |
| 3 Research design and methodology .....                              | 13 |
| 3.1 Research approach .....                                          | 13 |
| 3.2 Research structure .....                                         | 13 |
| 3.3 Data sources .....                                               | 14 |
| 3.4 Development of the morphological roof overview .....             | 15 |
| 3.5 QGIS labelling process .....                                     | 16 |
| 3.6 Data interpretation and DÂK 1.0 fit logic .....                  | 16 |
| 3.7 Product-family translation method .....                          | 17 |
| 3.8 Reliability, validity and limitations .....                      | 17 |
| 4 Morphological Roof Overview .....                                  | 18 |
| 4.1 Most important roof characteristics prefab roof renovation ..... | 18 |
| 4.2 Structure of the overview .....                                  | 19 |
| 4.3 How to use the Morphological Roof Overview .....                 | 20 |
| 4.4 Iteration history of the overview .....                          | 21 |
| 4.5 Expert validation and usable plausibility check .....            | 21 |
| 4.6 Expandability of the framework .....                             | 22 |
| 4.7 Defined DÂK 1.0 prefab roof profile .....                        | 22 |
| 5 Results of the MEER roof analysis .....                            | 23 |
| 5.1 Dataset and interpretation .....                                 | 23 |
| 5.2 Fit with the DÂK 1.0 prefab roof .....                           | 23 |
| 5.3 Dominant parameters for standardisation .....                    | 24 |
| 5.4 Parameters requiring adaptability .....                          | 24 |
| 6 Broader application to prefab roof renovation .....                | 25 |
| 6.1 Meaning for prefab roof companies .....                          | 25 |

|                                                              |    |
|--------------------------------------------------------------|----|
| 6.2 Basis for a modular roof architecture .....              | 26 |
| 6.3 From MEER dataset to national upscaling .....            | 26 |
| 6.4 Impact on engineering, production and installation ..... | 26 |
| 7 Discussion .....                                           | 27 |
| 7.1 Interpretation of the findings .....                     | 27 |
| 7.2 Standardisation versus custom renovation .....           | 27 |
| 7.3 Reliability and limitations .....                        | 27 |
| 7.4 Representativeness and wider application .....           | 27 |
| 7.5 Usability and scientific value .....                     | 28 |
| 8 Conclusion .....                                           | 28 |
| 9 Future vision .....                                        | 29 |
| 9.1 AI-supported roof recognition .....                      | 29 |
| 9.2 Roof type library .....                                  | 29 |
| 9.3 Extension to whole-house renovation .....                | 29 |
| 10 References .....                                          | 30 |
| 11 Appendices .....                                          | 31 |
| 11.1 Explanation of categories .....                         | 31 |
| 11.1.1 Context .....                                         | 31 |
| 11.1.2 Roof properties .....                                 | 33 |
| 11.1.3 Additions .....                                       | 36 |
| 11.2 Morphological overview Matthijs Petersen .....          | 39 |
| 11.3 Versions Morphological Roof Overview .....              | 40 |
| 11.3.1 Alternative clustering .....                          | 41 |

## Executive Summary

The Dutch housing stock requires large-scale renovation to improve energy performance, comfort and long-term sustainability. Prefab biobased roof renovation can support this transition because roof elements can be prepared off-site and installed more efficiently on-site. However, existing roofs are not identical. They differ in geometry, dimensions, roof covering, additions, installations and project context. This variation makes it difficult to move from project-specific renovation towards scalable prefab roof product families.

This research responds to that challenge by developing and applying a **Morphological Roof Overview**. The overview structures roof variation into three main categories: **context**, **roof properties** and **additions**. It is intended as an early-stage classification and analysis tool. It does not replace technical verification, but it helps make roof variation visible, comparable and usable for decision-making in prefab roof renovation.

The value of the Morphological Roof Overview is that it translates roof-stock data into structured product information. **Roof properties** show which prefab roof product-family directions are most common, for example through repeated roof types, dimensions, pitches and roof coverings. **Additions** show which modules and standard details are needed most often, such as solutions for roof windows, penetrations, dormers or solar panels. **Context** shows which dwellings or housing blocks are most suitable to start with, for example when similar roofs are repeated within one block or ownership situation.

The overview was applied to the dwellings involved in the MEER project using QGIS, available dimensional data, aerial imagery and Google Street View. The results show that many MEER dwellings fit the first DÂK 1.0 direction relatively well, because they share a similar basic roof logic: terraced or corner dwellings with tiled gable roofs. At the same time, the analysis shows that variation still exists within this group, especially in roof surface, pitch, silhouette, roof windows, penetrations and solar panels.

The research concludes that DÂK 1.0 should not be interpreted as one fixed roof product, but as the first direction within a broader prefab roof product family. The Morphological Roof Overview can support the development of DÂK 2.0 by showing where standardisation is possible, where adaptable variants or modules are needed, and where future roof families may be required. The results are specific to the MEER dwellings and are not representative of the full Dutch housing stock. For wider upscaling, the overview should be applied to larger and more varied roof-stock datasets, potentially supported by computer vision to recognise roof characteristics more efficiently.

# 1 Introduction

## 1.1 Project background

This research started from the MEER / DÂK programme by Building Balance. The MEER project aims to accelerate biobased prefab roof renovation by developing DÂK into an affordable, scalable and widely applicable renovation approach. Prefab means that roof elements are prepared or produced off-site and then installed on the dwelling on-site, which can reduce labour, installation time and project-specific work.

DÂK is developed in steps. DÂK 1.0 is the first prefab roof direction for relatively simple and repeatable roofs. DÂK 2.0 should make this solution more adaptable and easier to apply at scale. DÂK 3.0 is the longer-term ambition, with digital surveying, AI-supported decisions, further industrialisation and robotisation to reduce labour and costs even more (MEER Application Building Balance, 2025).

The order of magnitude is significant. The MEER / DÂK programme aims to move from pilot projects towards 10.000 renovated homes, with a longer-term potential of approximately 675.000 roofs. The programme sketches a development path from DÂK 1.0 in 2025, to DÂK 2.0 in 2027 and DÂK 3.0 in 2030. In this pathway, the intended labour demand decreases from 174 hours to 24,5 hours per dwelling, while the related labour cost indication decreases from approximately €14.790 to €2.083 per dwelling (MEER Application Building Balance, 2025).

At the start of the project, the assumption was that many post-war dwellings have roof characteristics that could fit a standard prefab roof direction, especially pitched tiled roofs from the 1965–1991 housing stock. However, variation in roof surface, pitch, silhouette and additions influences how far standardisation is possible (Building Balance, 2025). Without structured insight into this variation, it remains unclear which roofs can be renovated with a repeatable prefab solution, which require adaptable modules and where future roof families may be needed.

This makes roof variety analysis the relevant research field of this project. By systematically mapping and structuring existing roof characteristics, the research investigates how roof variation can be translated into usable input for scalable prefab renovation. The sustainability relevance lies mainly in accelerating energy renovation and enabling wider use of biobased roof solutions, although this research does not calculate the exact CO<sub>2</sub> or energy savings per dwelling.

## 1.2 Renovation challenge

Around 500,000 dwellings in the Netherlands were destroyed during the Second World War, which contributed to a severe housing shortage in the early 1950s (Centraal Bureau voor de Statistiek, 2025; Van Elk & Priemus, 1971). In 1956, the housing deficit was estimated at 188,000 dwellings, equal to 7.4% of the total housing stock (Centraal Bureau voor de Statistiek, 2025). This pressure led to the rapid development of large-scale and standardised post-war housing.

Today, many of these post-war dwellings no longer meet current standards for comfort and energy performance, while the Netherlands aims for all homes to be energy neutral by 2050 (Centraal Bureau voor de Statistiek, 2023; Ministerie van Algemene Zaken, 2019). Housing associations play an important role in this transition, as they own and rent out approximately 2.2 out of 8.3 million dwellings in the Netherlands (Woningonderzoek Nederland, 2024). The scale of this challenge creates a need to investigate renovation approaches that are more repeatable and less project specific. However, existing buildings still differ in geometry, construction, technical condition and surrounding context. Standardisation is therefore only possible when this variation is first made visible, structured and usable for decision-making (Lahfaji et al., 2024). Roofs are a relevant intervention point within this research, because roof performance influences thermal performance, indoor comfort and energy demand (Hofkes et al., 2005).

## 1.3 Problem: custom roof renovation versus scalable prefab

The problem addressed in this research also comes from the MEER / DÂK programme, where the ambition is to make biobased prefab roof renovation more repeatable, affordable and scalable. In practice, roof renovation is often approached with a high degree of project-specific assessment. This makes it possible to respond to specific building conditions, but it can also increase preparation time, engineering effort and labour demand (Nieuwenhuis, 2026). For prefab renovation to become more repeatable, recurring roof types, standard interfaces and adaptable product families need to be identified more clearly (TNO, z.d.).

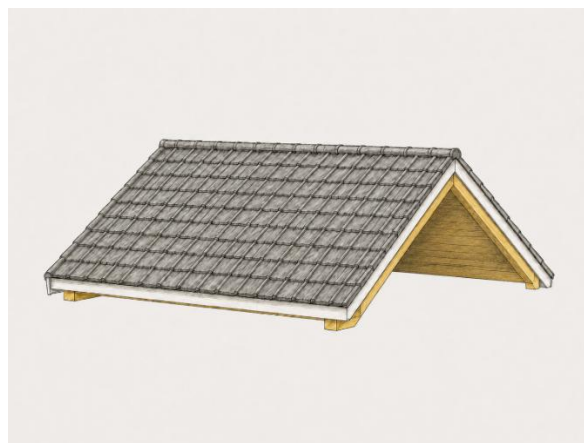
In this research, the main challenge is therefore not the existence of roof variation itself, but the lack of a structured and quantified overview that makes this variation usable for prefab decision-making. For prefab companies, relevant roof characteristics need to be known early enough to assess whether a roof fits the same product-family direction, requires a variant, or needs an additional module. Recurring deviations can then be translated into modules, variants or new roof families (Nieuwenhuis, 2026). This research responds to that challenge by systematically mapping roof characteristics and linking them to prefab renovation potential. The morphological overview is therefore used as an early-stage classification tool. It does not determine final technical suitability, but helps structure which roofs are likely to fit a standard product family, which require adaptation, and which require further technical verification. Figure 1 illustrates the prefab roof renovation principle used as a visual reference in this introduction.



*Figure 1. Prefab roof renovation*

#### 1.4 Building Balance / DÂK 1.0 as first standard direction

Building Balance responds to this challenge through the MEER project and the DÂK programme. Based on the MEER application, DÂK 1.0 is interpreted in this research as the first prefab product design within the DÂK programme: a biobased prefab roof solution aimed mainly at roofs with a relatively simple and repeatable geometry. This means roofs with a gable shape, a symmetrical cross-section, a common roof covering such as concrete roof tiles, a predictable roof surface and a roof pitch within a workable range. These characteristics are important because they influence the dimensions, segmentation, production, transport and installation of prefab roof elements. In this research, symmetrical tiled gable roofs are treated as a logical starting point for standardisation because their repeated roof geometry can be translated more directly into recurring element dimensions, segmentation and connection details. However, this first product design does not yet explain how other roof forms, different dimensions, additions, penetrations or less common roof configurations should be handled. Therefore, a broader method is needed to systematically map roof variation and determine which roofs can be solved with the current standard, which require adaptable modules, and which may need new roof families. (Building Balance, 2025) Figure 2 shows the DÂK 1.0 roof reference used in this research.



*Figure 2. DÂK 1.0*

## 1.5 Research aim and relevance

The aim of this research is to develop and apply a morphological roof overview that systematically categorises roof characteristics relevant to scalable prefabricated biobased roof renovation. DÂK 1.0 is mainly the prefabricated product design for the first promising MEER category: tiled gable roofs with a relatively repeatable geometry. This research provides the broader method behind that direction. It maps roof types systematically so standard roofs can be selected and other roofs can be evaluated for modules, variants or future roof families.

Because the method uses fixed categories, it could support future AI-assisted roof recognition. In that future application, visual recognition methods could identify roof characteristics such as roof type, silhouette and additions, after which the morphological overview could structure these characteristics for prefabricated decision-making. This application is outside the scope of the current research and would require separate validation.

## 1.6 Intended audience and professional products

The primary audience of this roof analysis consists of prefabricated roof companies and stakeholders in the MEER/DÂK programme who need to translate existing roof variation into product-family decisions. The main professional product of this research is the morphological roof overview. The MEER roof analysis functions as a case application of this framework, while the advice report translates the findings into practical recommendations for DÂK 1.0 and future product-family development.

## 1.7 Research question, sub-questions and scope

**How can existing roof variation stock data be systematically categorised and analysed to identify opportunities for standardisation and adaptability in scalable prefabricated biobased roof renovation, and how can this be verified within the MEER project?**

To answer this main question, the following sub-questions are used:

**SQ1. Which roof characteristics are relevant for prefabricated roof renovation?**

**SQ2. How can these roof characteristics be systematically structured into an overview which supports decision making in prefabricated roof renovation?**

**SQ3. What roof variation is present in the MEER project?**

**SQ4. Which roof characteristics within the MEER project show potential for standardisation, and which require adaptability?**

**SQ5. How can the results be translated into usable input for prefabricated roof companies?**

The research analyses include 1,480 pitched roofs in the MEER dataset. It does not include detailed engineering, structural calculations, cost calculations per roof or final technical suitability checks. The framework is designed to be transferable to other datasets, but this transferability has not been validated within this research. Table 1 shows how the sub-questions are answered in the report.

*Table 1. Sub-questions table*

| Sub-question | Answered mainly in    | Method                                             | Function                                    |
|--------------|-----------------------|----------------------------------------------------|---------------------------------------------|
| SQ1          | Chapter 2.3 & 4.1     | Literature, roof variety analysis and expert input | Defines relevant characteristics            |
| SQ2          | Chapter 3.4 & 4.2–4.7 | Requirement-based development and iteration method | Structures the overview                     |
| SQ3          | Chapter 5.1–5.2       | QGIS labelling and descriptive analysis            | Shows roof variation in MEER                |
| SQ4          | Chapter 5.3–5.4       | DÂK 1.0 fit logic and parameter comparison         | Interprets standardisation and adaptation   |
| SQ5          | Chapter 3.7 & 6       | Product-family translation method                  | Translates results into prefabricated input |

## 2 Research context and theoretical background

This chapter explains the project context and theoretical basis that informed the morphological overview. It connects the renovation challenge from the introduction to the need for a structured classification method.

### 2.1 MEER / DÂK project context

This research is positioned within the MEER project and the DÂK programme by Building Balance. The goal of MEER is to accelerate the upscaling of biobased roof renovation by developing DÂK into an affordable, scalable and widely applicable market standard. The programme responds to the current situation in which biobased roof renovations are still too expensive, too dependent on separate pilots and difficult to scale across the renovation market.

According to the MEER application, the programme targets 10,000 renovated homes, an upscaling potential of 675,000 roofs, 150 parties equipped to apply the biobased roof, an intended labour reduction of 86%, and a cost reduction from approximately €14.790 to €2.083 per dwelling. These numbers are not outcomes of this research, but they define the scale and ambition against which the relevance of a repeatable roof classification method is assessed. Table 2 summarises the related timeline, labour reduction and cost indication used as project context.

Table 2. Goals Building Balance hours saved VGO (maintenance party) DÂK 1.0, 2.0 and 3.0

|                                               | Reference projects 2024* | DÂK 1.0 2025 | DÂK 2.0 2027 | DÂK 3.0 2030               |
|-----------------------------------------------|--------------------------|--------------|--------------|----------------------------|
| Selection of suitable roofs                   | 0                        | 0            | 0            | 0.25 (quota)               |
| Recording and measuring                       | 2                        | 2            | 1            | 0.5 (digital)              |
| Scenario analysis                             | 2                        | 1            | 0.5          | 0.5 (AI)                   |
| Engineering                                   | 8                        | 4            | 2            | 0.5 (AI/digital surveying) |
| Work preparation                              | 2                        | 2            | 1            | 0.75                       |
| Installation/assembly roof/ridge/gutter/tiles | 64                       | 48           | 32           | 16 (robotisation)          |
| Heat pump installation                        | 64                       | 32           | 16           | 4 (installed in the roof)  |
| Solar panel installation                      | 16                       | 16           | 8            | 0 (BIPV)                   |
| Loss of continuity                            | 10                       | 8            | 4            | 2                          |
| Administration/project control                | 6                        | 6            | 4            | 0.5 (ai)                   |
| Total                                         | 174                      | 113          | 57.5         | 24.5                       |
| Costs at €85/hour                             | €14,790                  | €9,605       | €4,888       | €2,083                     |
| Savings compared to 2024                      |                          | 35%          | 67%          | 86%                        |

\* For all roofs, this calculation is based solely on the roof without installations. A Unidek roof is used as a reference.

(MEER Application Building Balance, 2025)

For this research, especially the upscaling and decision-making goals are relevant. To renovate roofs at this scale, prefabricated companies need to know which roof situations fit the current DÂK direction, which roofs require adaptable modules, and which roof types may need future roof families. The morphological roof overview supports this by structuring roof variation into fixed categories. In this way, the overview functions as a bridge between MEER's ambition for a market standard and the practical need to select, cluster and translate existing roofs into prefabricated product strategies.

## 2.2 Prefab biobased roof renovation

Prefab roof renovation means that large parts of the roof system are prepared off-site and installed on-site as prefabricated roof elements. Instead of constructing or adapting the full roof on the building itself, the roof element is designed and produced beforehand in a controlled production environment. This can reduce on-site labour, shorten the installation phase and improve repeatability, especially when similar roof types are renovated across multiple dwellings or housing blocks (TNO, z.d.; MEER Application Building Balance, 2025).

In biobased prefab roof renovation, the prefabricated elements are partly or fully made with biobased materials, such as timber-based structures or insulation materials from renewable resources. Within the MEER project, this approach is explored as a way to combine faster renovation with a lower environmental impact. The aim is therefore not only to improve the energy performance of existing dwellings, but also to reduce the dependency on conventional, high-impact building materials (MEER Application Building Balance, 2025; interviews with R. Lateveer, R. Ebbers and L. Andringa, 2026).

The general process of prefab roof renovation is shown in Figure 3. The process starts with understanding the existing roof variation by gathering data, inspecting the roof condition, measuring dimensions and defining relevant attachment points. This is the focus of this research report. This information is then used to adapt the prefab roof element to the specific dwelling. After this, the element can be prefabricated off-site. On-site, the roof is prepared by removing the old roof covering and preparing the attachment points. The prefab element is then mounted onto the existing roof structure. The process ends with a final check to ensure that the roof element, connections and finishing work function correctly. This sequence shows why accurate data gathering at the start is important: decisions made before production influence the feasibility, efficiency and quality of the installation phase.

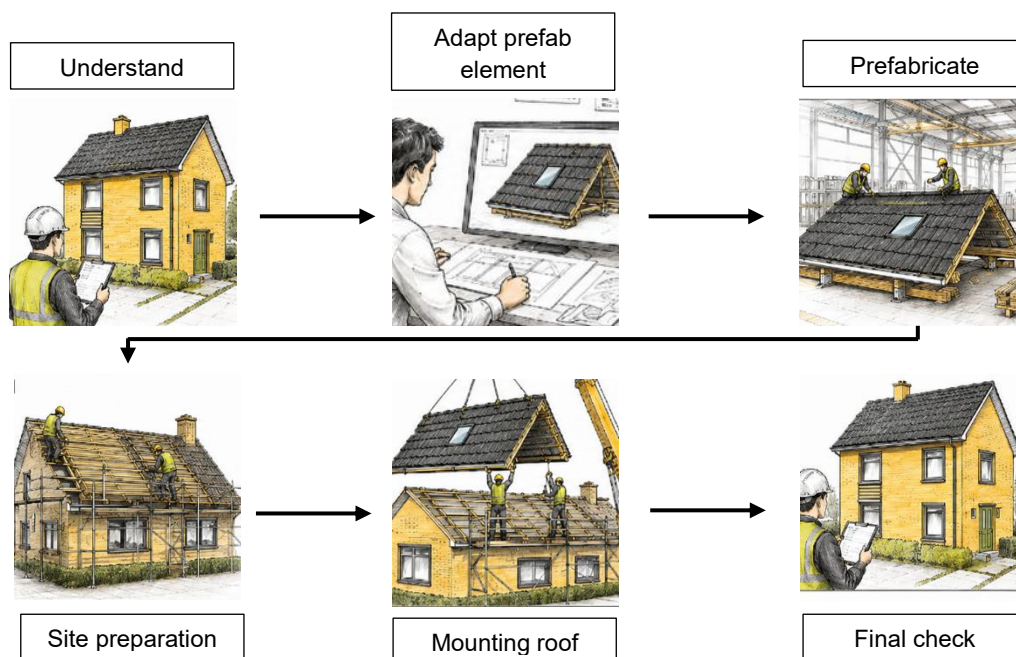


Figure 3. Prefab roof renovation process

## 2.3 Roof variety analysis

Before developing the Morphological Roof Overview, roof variety was explored through visual analysis of existing dwellings. This showed that roof variation is not only caused by the main roof shape, but also by a combination of roof type, roof covering, roof silhouette, openings, penetrations and technical installations. Figures 4 and 5 show examples of this variation, including gable roofs, hip roofs, mansard roofs, flat roofs, dormers, roof windows, chimneys, flue gas outlets, heat pumps and solar panels. These elements are relevant because they influence

whether a prefab roof solution can be repeated directly, adapted with modules, or requires further technical checks.



Figure 4. Roof variety overview

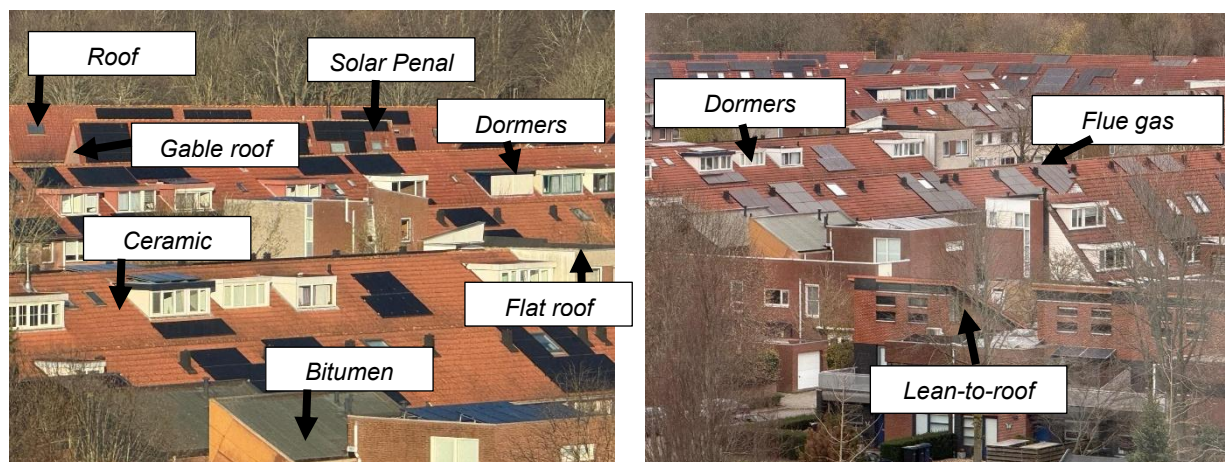


Figure 5. Roof variety 1950 - 1990 dwellings

The analysis was also linked to the function of a roof. According to the Delft Design Guide, defining the main function and sub-functions of a system helps to structure a morphological analysis (Van Boeijen et al., 2013). In this research, the main function of the roof is understood as protecting the building and its users from weather conditions. Sub-functions include insulation, water drainage, structural stability, comfort and appearance. This explains why the overview includes not only roof shape, but also roof components related to openings, penetrations, covering, drainage and installations.

The visual roof variety analysis is supported by Petersen's (2025) morphological dwelling overview, based on 19.711 scanned dwellings. However, this dataset has a clear selection bias. It does not represent the full Dutch housing stock, because it was filtered for dwellings that are relevant for industrialised prefab renovation. The selected dwellings are ground-bound terraced houses with a gable roof, built between 1946 and 1991, with energy

label C or worse and an exploitation period beyond 2050. This means that other housing types, such as apartments, detached houses, semi-detached houses, newer dwellings, older dwellings, privately owned dwellings and non-gable roof types are underrepresented or excluded. Petersen's full morphological overview is included in Appendix 11.2 as Figure 16.

Within this selected target group, Petersen's overview still shows that roof variation is present. Symmetrical silhouette variants occur in 4,221 dwellings, or 21.4% of the scanned dwellings. Smaller groups show more complex roof shapes, such as flat-roof or single-pitched deviations, and unusual or strongly deviating silhouettes. These categories occur less often, but they are important because they may require different prefabricated element shapes, edge details or even a separate product-family direction.

The same overview also shows that additions and roof interfaces are recurring sources of variation. Roof windows are common, with 64.2% of the dwellings having one roof window and 35.8% having multiple roof windows. Installations or solar panels are present on 16.6% of the dwellings, while 18.3% have an extension that can influence the roof connection. Therefore, Petersen's data should not be used as proof of the full roof variety in the Netherlands, but as supporting evidence that even within a filtered and prefabricated-relevant target group, roof variation remains important for standardisation, modules and future product-family development.

## 2.4 Morphological analysis

Morphological analysis structures complex design problems by breaking them down into categories, parameters and possible variations (Leupen & Mooij, z.d.). In this research, morphological analysis is used to make roof variation comparable by describing each roof through the same set of categories.

The overview is divided into three main categories: context, roof properties and additions. Context describes project conditions such as house type and ownership. Roof properties describe the physical fit, such as roof type, silhouette, surface area, pitch and covering. Additions describe interruptions such as dormers, roof windows, penetrations and installations. The choice of categories influences the results: a different categorisation could lead to different groupings or different interpretations of standardisation potential.

This method supports the main goal of the research: distinguishing between roofs that fit DÂK 1.0 directly, roofs that need modules or variants, and roofs that require a new roof family. It builds on previous morphological housing research by Petersen (2025), but focuses more specifically on roof geometry, interfaces and roof additions.

## 2.5 Alternative methods for roof classification

Several methods can be used to classify or analyse roofs, such as technical inspections, data-driven clustering or computer vision-based component detection. For example, Walraven (2024) explores the automation of façade quickscans by detecting and segmenting architectural components from street-view imagery. This type of approach is useful for identifying separate building elements, but it does not provide the same type of morphological structure as required in this research.

For this research, a morphological overview was selected because the aim is not only to recognise individual components, but to structure roof variation in relation to prefabricated renovation decisions. The overview combines roof type, roof shape, additions, installations, dimensions and interfaces in one framework. This makes it possible to compare roofs beyond separate components and to relate recurring roof characteristics to standard modules, variants or future roof families. This also fits a Systems Engineering approach, where the roof is treated as a system of related elements rather than as a collection of isolated parts (Bonnema et al., 2016).

### 3 Research design and methodology

This chapter explains how the research question was translated into a repeatable method. The process moves from defining relevant roof characteristics to labelling the MEER dataset and defining how the labelled data is interpreted in relation to DÅK 1.0.

#### 3.1 Research approach

This research was approached from a systems engineering perspective. The roof was not analysed as an isolated building part, but as part of a larger prefabricated renovation system. Roof characteristics were therefore selected based on their influence on the full renovation process: selection, engineering, production, transport, installation and future upscaling.

From this perspective, roof variation is not only a technical problem, but also a system problem. A roof with a standard geometry may still be difficult to renovate when ownership is fragmented, when many additions interrupt the roof surface, or when technical information is missing. At the same time, roofs that are not identical may still be suitable for one prefabricated product family when their variation can be translated into standard modules or dimensional variants.

This approach connects the morphological overview to the practical workflow of prefabricated roof companies: each selected category must support early decision-making about standardisation, adaptation or further technical verification.

#### 3.2 Research structure

The research process was structured using the Double Diamond framework: Discover, Define, Develop and Deliver (Design Council, 2005). This structure was used because the project first required a broad understanding of roof variation and prefabricated renovation, before this variation could be structured, applied to the MEER dataset and translated into practical conclusions. Figure 6 summarises the research structure.

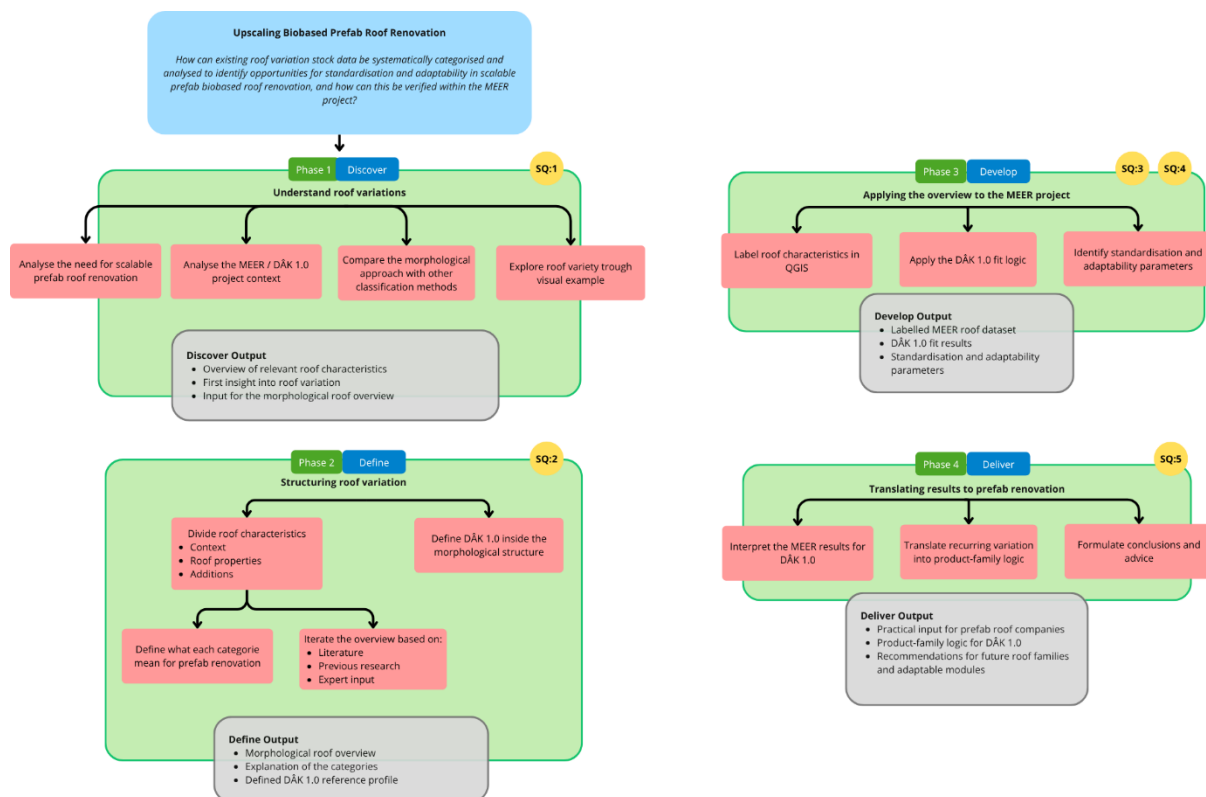


Figure 6. Research diagram

In the **Discover** phase, the renovation challenge, MEER project context and prefab roof renovation were explored. Literature, MEER project documentation, previous morphological housing research and expert input were used to identify which roof characteristics influence prefab renovation. This phase mainly answered SQ1: Which roof characteristics are relevant for prefab roof renovation?

In the **Define** phase, the relevant roof characteristics were structured into the morphological roof overview. The overview was divided into three main categories: context, roof properties and additions. This created a fixed structure for describing roof variation and made it possible to compare roofs in a consistent way. This phase answered SQ2: How can these roof characteristics be systematically structured into an overview which supports decision making in prefab roof renovation?

In the **Develop** phase, the morphological roof overview was applied to the MEER dataset. The roofs were labelled and analysed to identify dominant roof characteristics, recurring roof types and parameters that require adaptation. This phase answered SQ3: What roof variation is present in the analysed MEER dataset?

In the **Deliver** phase, the results were translated into conclusions for prefab roof renovation. The analysis was used to distinguish between characteristics that support standardisation and characteristics that require adaptability. It also provided input for the advice report and for the further development of DÂK 1.0 as a prefab roof product family. This phase answered SQ4 and SQ5.

### 3.3 Data sources

Several data sources were used during the research. Literature about roof construction, housing typologies, prefab renovation, morphological analysis and mass customisation was used to define which characteristics are relevant for prefab roof renovation. Previous morphological housing research by Petersen (2025) was used as a starting point for structuring variation, but the framework was further developed specifically for roofs and prefab renovation.

MEER project documentation from Building Balance was used to understand the ambitions of the DÂK programme. This included the focus on biobased renovation, standardisation, industrialisation, cost reduction, labour reduction and large-scale implementation. This project context was important because the morphological overview had to support practical decisions for DÂK 1.0 and future roof families.

Expert and stakeholder input was used to check whether the morphological roof overview was practically relevant for prefab roof renovation. The expert input came from three people who were involved in, or connected to, the MEER / DÂK roof renovation context.

Rogier Lateveer was involved as company supervisor from Hogeschool Utrecht and as a researcher within the applied urban energy transition context. His background in architecture and renovation helped translate the roof analysis into building-related terminology and practical renovation logic. His input was useful for understanding how roof characteristics influence the renovation process and how the overview could be aligned with the MEER / DÂK programme.

Rick Ebberts contributed from a practical prefab roof renovation perspective. He graduated as a construction engineer, which made his input especially useful for checking whether the roof characteristics were technically and practically relevant for prefab roof renovation.

Lieven Andringa contributed from the project and implementation side of prefab roof renovation. As project leader of the MEER project, his input helped assess whether the morphological roof overview could support practical decision-making within the MEER / DÂK context.

In addition to these expert discussions, the morphological roof overview was presented during a stakeholder meeting on 3 June 2026. The audience consisted of a broad group of professionals from the building and renovation sector, including housing associations, renovation and maintenance companies, RGS/VGO organisations, suppliers, consultants, knowledge organisations and data-related parties. This meeting functioned as a practical plausibility check. The discussion helped assess whether the structure of the overview was understandable for professionals and whether the categories were relevant for early-stage decision-making in scalable prefab roof renovation.

The quantitative analysis was based on the MEER dataset of 1,480 pitched roofs. This dataset included addresses and available dimensional information. Additional visible characteristics were labelled manually using QGIS, aerial imagery and Google Street View.

### 3.4 Development of the morphological roof overview

The morphological roof overview was developed as an early-stage classification framework to make roof variation visible, comparable and usable for prefabricated renovation decisions. It is not intended as a final technical inspection tool, but as a method to support selection, clustering and product-family development.

The development started with a program of requirements. The most important requirements were that the overview had to be relevant for prefabricated roof renovation, easy to use by different stakeholders, and useful for showing quantity differences within a selected housing stock. In addition, the overview had to give a clear overview of roof variation, support decisions between standardisation and adaptation, and be expandable for future use. Table 3 shows the requirements used during the development.

*Table 3. Requirements for the Morphological Roof Overview*

| Subject           | Requirement                                                                                                     | Check                                                                                    |
|-------------------|-----------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|
| Relevance         | The overview must include parameters that influence prefabricated roof renovation.                              | Parameters relate to standardisation, adaptation, modules or product-family development. |
| Usability         | The overview must be understandable for prefabricated roof companies, project leaders and housing associations. | Clear terminology and logical categories.                                                |
| Quantity analysis | The overview must show which roof characteristics occur most often.                                             | Characteristics can be counted and compared.                                             |
| Roof variation    | The overview must give insight into variation between roofs.                                                    | Differences in context, roof properties and additions are visible.                       |
| Decision-making   | The overview must support decisions about standardisation versus adaptation.                                    | Results can be translated to product-family directions, modules or further checks.       |
| Expandability     | The overview must be expandable for future use.                                                                 | New parameters can be added when more data becomes available.                            |
| Validation        | The overview must be tested on real housing-stock data.                                                         | Applied to MEER dwellings and checked with experts.                                      |

The overview was developed from literature, MEER / DÂK project information, expert input and visual analysis of existing dwellings. The selected parameters therefore had to be both practically recognisable and relevant for prefabricated renovation.

Several structures were considered during the development. A mainly technical structure gave insight into roof geometry, but less into project scalability. A mainly contextual structure was useful for housing associations, but gave too little input for prefabricated product design. Therefore, the final overview was divided into three categories: context, roof properties and additions. Context shows which dwellings or blocks are suitable for large-scale organisation. Roof properties show which prefabricated roof product-family directions are most relevant. Additions show which modules or standard details are needed around the base prefabricated roof.

The iteration process followed a requirement-based method. First, a version of the overview was made from literature, visual roof analysis and MEER / DÂK input. Second, this version was checked against the requirements in Table 3 and validated with expert interviews. Third, the overview was tested on roof examples to see whether the categories could be filled in consistently. Fourth, unclear, overlapping or less useful parameters were changed, merged or removed. This cycle was repeated until the overview was usable for analysing the MEER roof variation.

The main changes during the iterations were related to terminology, category structure and decision value. For example, general housing types such as semi-terraced house were changed into roof-relevant dwelling positions like corner house, because these better support clustering at housing-block level. Additions were expanded because roof windows, dormers, penetrations and solar panels often determine where standard modules or details are needed. In this way, the overview was developed as a bridge between roof-stock data and prefabricated roof product-family decisions.

### 3.5 QGIS labelling process

QGIS was used as the main tool to organise and label the MEER roof dataset. First, the addresses of the dwellings involved in the MEER project were imported into QGIS. The categories from the morphological roof overview were then added as attributes, so every dwelling could be labelled in the same structured way. Figure 7 shows an example of the QGIS labelling environment.

Some data was already available and only had to be linked to the correct dwelling records. This mainly included dimensional information, such as roof surface. Other characteristics were labelled manually through visual interpretation. This was done using aerial imagery, Google Street View and available map data.

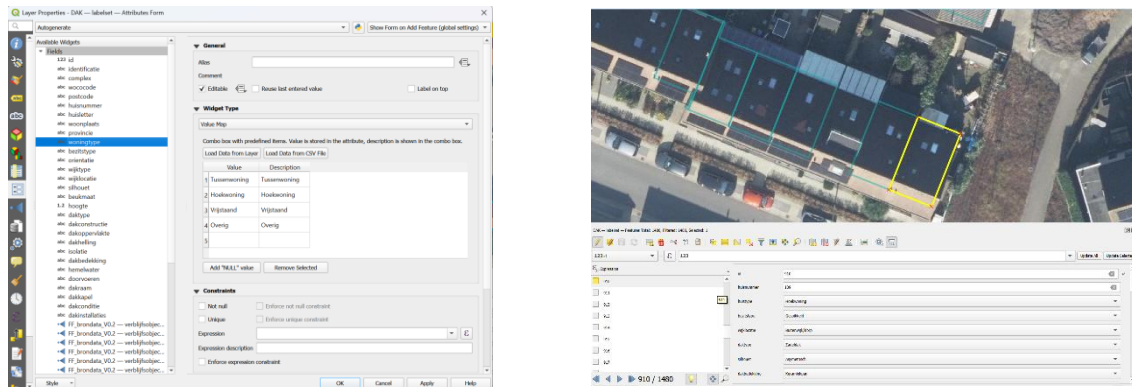


Figure 7. QGIS labelling

The labelling was performed by one researcher. No inter-rater reliability test was conducted, which limits the reproducibility of the manual visual labels. The manually labelled characteristics included house type, ownership type, roof type, silhouette, roof covering, rainwater drainage, roof penetrations, roof windows, dormers, roof condition and visible roof installations. These characteristics were selected because they are relevant for early prefabrication selection and can often be identified visually.

Not all characteristics could be labelled reliably. Roof construction, existing insulation, structural condition and detailed interfaces could not be determined from visual sources alone. These characteristics require drawings, scans, site inspection or technical information from housing associations. Therefore, they were not used as hard criteria in the quantitative fit with DÂK 1.0.

### 3.6 Data interpretation and DÂK 1.0 fit logic

The labelled dataset was analysed to determine how the MEER roofs relate to the defined DÂK 1.0 prefabrication roof profile. The DÂK 1.0 profile was defined in the morphological overview as a pitched tiled gable roof for terraced and corner dwellings, with a roof surface around 50 m<sup>2</sup> and a roof structure that can remain in place.

For the quantitative comparison, only the characteristics that could be identified from the dataset were used. These were house type, roof type, roof covering and roof surface. Roof construction is part of the theoretical DÂK 1.0 profile, but it was excluded from the quantitative fit because it could not be verified through QGIS, aerial imagery or Street View.

The analysis was structured into three interpretation groups. Roofs that matched the main DÂK 1.0 characteristics and had a roof surface between 40 and 60 m<sup>2</sup> were interpreted as the most direct fit. Roofs that matched the main DÂK 1.0 direction but had a larger, smaller or uncertain roof surface were interpreted as needing adaptation or further checks. Roofs that did not match the main direction of terraced or corner dwellings with tiled gable roofs were interpreted as needing a different design direction.

This interpretation makes the later analysis more useful for prefabrication roof companies. It avoids a simple suitable/not suitable classification and instead shows where the standard base can be repeated, where dimensional variants or modules are needed, and where future roof families may be required.

### 3.7 Product-family translation method

To answer sub-question 5, the output of the morphological roof overview was translated into practical input. This was done by linking the three categories of the overview to different prefabricated renovation decisions. Roof properties were translated into possible prefabricated roof product-family directions, because they influence the main shape, dimensions, pitch, covering and segmentation of the roof element. Additions were translated into possible modules, standard details or adaptation needs, because they can interfere with the standard prefabricated roof surface. Context was translated into project-selection input, because repeated house types, housing blocks and ownership situations influence where large-scale renovation can start most easily.

The translation was by comparing the dominant MEER roof characteristics with the defined DÂK 1.0 prefabricated roof profile. Roofs that matched the main direction were interpreted as potential standardisation groups. Roofs with the same main direction but different dimensions or additions were interpreted as adaptation groups. Roofs outside the main direction were interpreted as possible input for future roof families. In this way, the method connects the roof-variety analysis to practical decisions about standard elements, modules, variants and future development directions.

### 3.8 Reliability, validity and limitations

The method is suitable for early-stage classification because the variables used in the quantitative fit logic, such as house type, roof type, roof covering and roof surface, were visible or available in the dataset. However, it is not suitable for final engineering verification. Key technical variables, including roof construction, existing insulation, structural condition, material quality and detailed interfaces, could not be verified from aerial imagery, Google Street View or QGIS data.

The reliability of the analysis is therefore limited by the quality and availability of the visual data. Some roofs were partly hidden by trees, neighbouring buildings or poor viewing angles, while some Street View images were blurred, outdated or unavailable. As a result, smaller elements such as roof penetrations, vents, roof windows or roof-edge details may not always have been visible. The absence of a visible element should therefore not be interpreted as proof that the element is not present. Figure 8 shows an example of a blurred Street View image that limits visual interpretation.



*Figure 8. Blurred Google Street View example*

The validity of the method was supported by literature, MEER documentation, expert input and stakeholder feedback. These sources confirmed that the selected categories are relevant for prefabricated roof renovation and can support early selection, clustering and product strategy. Still, the results should be interpreted as an indication of prefabricated potential, not as a final technical assessment. Further implementation requires verification through drawings, scans, site inspection or housing association data.

Finally, the quantitative analysis is specific to the MEER dataset. The dataset is relevant for the DÂK context, but it is not representative of the full Dutch housing stock. Therefore, the results cannot automatically be generalised to all Dutch roofs. The broader value of the research lies in the morphological framework, which can be applied to larger and more varied datasets in future research.

## 4 Morphological Roof Overview

This chapter presents the main output of the method: the morphological roof overview. The overview is used to describe roof variation in a structured way before it is applied to the MEER dataset.

### 4.1 Most important roof characteristics prefab roof renovation

The most important roof characteristics for prefab roof renovation are the characteristics that influence the fit, design and adaptability of a prefab roof solution. From a systems engineering perspective, the roof can be seen as a system of related elements that influence selection, engineering, production and installation (Bonnema et al., 2016).

The basic roof geometry is the first important factor. Roof type, silhouette, roof pitch and roof surface determine the shape, dimensions and segmentation of the prefab roof element. These characteristics influence whether a roof can be approached with a standard element or whether dimensional variants are needed (Building Balance, 2025; interviews with R. Lateveer, R. Ebbers and L. Andringa, 2026).

Roof build-up and finish are also relevant. Roof covering, insulation, drainage and existing roof structure influence how the prefab element connects to the existing building and how the roof performs in relation to weather protection, insulation and water drainage (Hofkes et al., 2005; Van Boeijen et al., 2013).

Finally, additions such as dormers, roof windows, chimneys, flue gas outlets, ventilation pipes and solar panels are important because they interrupt the standard roof surface. These elements do not automatically exclude prefab renovation, but they show where adaptable modules, standard details or further technical checks are needed (interviews with R. Lateveer, R. Ebbers and L. Andringa, 2026). Figure 9 visualises these recurring roof components.



Figure 9. Variety overview roof components

The structure separates context, roof properties and additions because these categories influence different decisions in prefab renovation. Context affects project organisation and scalability, roof properties affect the base element design, and additions affect modules, details and technical checks. Figure 10 shows the full Morphological Roof Overview.

Gemaakt door: Jorden Adolfo  
Lectionaat: Nieuwe Energie in de Stad  
22-05-2026

Figure 10. Morphological roof overview

|               |                                                                                     |        |                                                                                     |        |                                                                                     |        |                                                                                     |        |  |  |                                                         |
|---------------|-------------------------------------------------------------------------------------|--------|-------------------------------------------------------------------------------------|--------|-------------------------------------------------------------------------------------|--------|-------------------------------------------------------------------------------------|--------|--|--|---------------------------------------------------------|
| 1.1 Housetype | Terraced house                                                                      |        | Corner house                                                                        |        | Detached house                                                                      |        | Other                                                                               |        |  |  | The positioning of a dwelling within the urban context. |
|               |  |        |  |        |  |        |  |        |  |  |                                                         |
|               | 1.1.1                                                                               | Number | 1.1.2                                                                               | Number | 1.1.3                                                                               | Number | 1.1.4                                                                               | Number |  |  |                                                         |

Page 19

The roof type part of the roof properties category is shown in Figure 12. Roof properties describe the physical characteristics of the roof, such as roof type, silhouette, roof structure, surface area, height, span width, pitch, insulation configuration, roof covering and rainwater drainage. These parameters are important because they influence the geometry, segmentation, structural fit and production possibilities of prefab roof elements.

|               |            |        |          |        |              |        |              |        |           |        |       |                            |
|---------------|------------|--------|----------|--------|--------------|--------|--------------|--------|-----------|--------|-------|----------------------------|
| 2.1 Roof type | Galbe roof |        | Hip roof |        | Mansard roof |        | Lean-to roof |        | Flat roof |        | Other | General shape of the roof. |
|               | 2.1.1      | Number | 2.1.2    | Number | 2.1.3        | Number | 2.1.4        | Number | 2.1.5     | Number |       |                            |

Figure 12. Morphological Roof Overview - Roof properties - Roof type

The penetration part of the additions category is shown in Figure 13. Additions describe elements that may be present on the roof, such as roof penetrations, roof windows, dormers, roof condition and roof installations. These additions are important because they often interrupt the standard roof surface and determine where a prefab solution needs adaptable details or additional technical checks.

|                  |                 |        |         |        |             |        |        |        |            |        |       |        |                                                         |
|------------------|-----------------|--------|---------|--------|-------------|--------|--------|--------|------------|--------|-------|--------|---------------------------------------------------------|
| 3.1 Penetrations | Flue gas outlet |        | Chimney |        | Ventilation |        | Cables |        | Sewer vent |        | None  |        | Elements that physically pass through the roof surface. |
|                  | 3.1.1           | Number | 3.1.2   | Number | 3.1.3       | Number | 3.1.4  | Number | 3.1.5      | Number | 3.1.6 | Number |                                                         |

Figure 13. Morphological Roof Overview - Additions - Penetrations

Together, the three categories create a layered understanding of roof variation. Context explains whether renovation can be organised efficiently, roof properties define the basic product fit, and additions show where a standard roof surface may need modules or additional checks. The full morphological roof overview and the explanation of all categories are included in Appendix 11.1 Morphological roof overview and Appendix 11.1.1 Explanation of categories.

### 4.3 How to use the Morphological Roof Overview

The Morphological Roof Overview is used to structure roof variation in a selected housing stock. First, the stakeholder defines which dwellings or housing blocks will be analysed. This can be one project, one housing-association portfolio or a larger roof-stock dataset. The results always have to be interpreted within this selected scope.

The next step is to gather the data needed for the three categories: context, roof properties and additions. This data can come from housing-association records, drawings, QGIS, aerial images, Google Street View, site inspections or existing datasets. In the future, computer vision could support this process for visible characteristics such as roof type, roof windows, dormers, penetrations and solar panels. However, technical verification remains necessary for hidden characteristics such as construction, condition and structural capacity.

After the data is collected, every roof is labelled using the same categories and definitions. This makes the roofs comparable. The filled-in overview can then be used to count how often each characteristic occurs. The aim is not to make a perfect go/no-go decision, but to understand where the largest recurring groups and most important variations are.

For prefab roof companies, the roof properties category is the most important. It shows which prefab roof product-family directions are most relevant, for example through repeated roof types, dimensions, pitches and coverings. These outcomes can inform the shape, dimensions and segmentation of standard prefab roof elements.

The additions category shows which modules or standard details are needed around the base prefab roof. Roof windows, dormers, penetrations and solar panels can interfere with a standard roof element. When these additions occur often, they should be translated into repeatable modules, details or engineering checks instead of being solved separately for every project.

For project leaders and housing associations, the context category is especially relevant. It shows which dwellings or housing blocks are easier to renovate at scale, for example because they have similar house types, repeated roof forms or continuous ownership. This helps identify where prefab renovation can start with the least organisational complexity.

In this way, the overview helps stakeholders move from individual roof assessment towards structured roof-variety analysis. It shows where standardisation is possible, where adaptation is needed and where future roof families may be required.

#### 4.4 Iteration history of the overview

The morphological roof overview was developed through several iterations. Earlier versions mainly listed visible roof and dwelling characteristics, but the final version was made more systematic and better aligned with prefabricated roof renovation. The focus shifted from general building descriptions to characteristics that influence the design, applicability and adaptability of a prefabricated roof solution. The main previous versions are included in Appendix 11.3 as Figure 17.

One important change was the house type category. Earlier versions used dwelling types such as terraced house and semi-detached house. However, for roof renovation, the roof condition is more relevant than the general dwelling type. For example, a semi-detached house can be interpreted as two corner houses, because both dwellings have an end condition that affects roof edges, detailing and connections. Therefore, the category was changed towards roof-relevant dwelling positions, such as terraced dwellings and corner dwellings. Figure 14 shows an earlier version of this category.

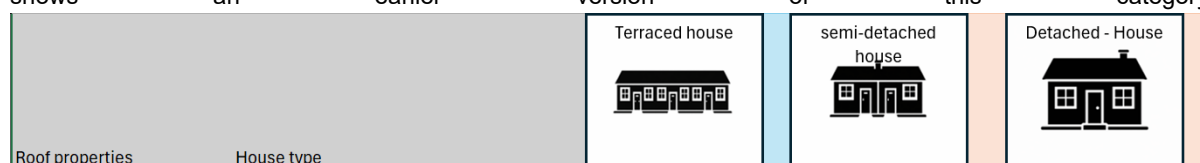


Figure 14. Previous version of the house type category

Another change was made in the existing insulation category. The earlier distinction between warm roof, cold roof and mixed roof was replaced by internal and external insulation, because this better describes how the existing roof build-up influences the prefabricated renovation approach.

The overall structure was also revised into the three main categories: context, roof properties and additions. This makes clear which factors describe the renovation conditions, which describe the physical roof, and which describe interruptions such as penetrations, installations, roof windows or dormers.

The iterations moved the overview from a descriptive building inventory towards a decision-oriented classification framework. Categories were kept when they helped assess prefabricated fit, required adaptation, or indicated the need for further technical verification.

#### 4.5 Expert validation and usable plausibility check

The morphological roof overview was validated through literature, expert input and stakeholder feedback. Housing typology and roof construction literature supported the division into context, roof properties and additions, because these sources describe dwelling configurations, roof types, roof construction, openings, covering and drainage (Leupen & Mooij, z.d.; Hofkes et al., 2005).

Expert interviews with Rick Ebbers, Rogier Lateveer and Lieven Andringa confirmed that prefabricated roof suitability is not only determined by roof geometry. Characteristics such as roof surface, slope, ownership, penetrations, roof windows, dormers and installations also influence engineering, production, logistics and installation. Especially additions were confirmed as important complexity factors, because they interrupt the standard roof surface and often require adaptable prefabricated details.

Feedback from Rick Ebbers further validated the practical direction of the Morphological Roof Overview. He recognised the visual and content development of the overview and confirmed that the selected categories connect well to the D&A concept and the development questions within the programme. His feedback also clarified that the value of the overview should not be framed as producing a hard GO/NOGO decision. Instead, the overview should make deviations from the current D&A direction visible, so that different users, such as developers, housing associations, maintenance parties and contractors, can interpret the results in relation to their own project conditions. This supports the interpretation of the overview as an early-stage analysis and discussion tool, rather than as a final decision or engineering tool.

The overview was also presented on 3 June 2026 during a stakeholder meeting with approximately 60 stakeholders from the building industry. The audience recognised the main categories, understood the standard roof profile and confirmed that the overview can support early selection, clustering and discussion about standardisation potential. Figure 15 shows the stakeholder meeting used for this practical plausibility check.



*Figure 15. Stakeholder meeting, 3 June 2026*

At the same time, the validation confirmed that the overview is not sufficient for final engineering decisions. Visual roof analysis can support early product strategy but must be followed by technical verification of roof construction, insulation, structural condition and detailed interfaces before implementation.

## 4.6 Expandability of the framework

The morphological roof overview is designed as an expandable framework. New categories can be added when more detailed data becomes available, for example about structural connections, roof condition, installation zones, façade interfaces or technical inspection results. This makes the overview useful beyond the current MEER analysis and allows it to develop with future prefab roof families.

The fixed categories may make the framework suitable for future AI-supported roof recognition, but this has not been tested in this research. Roof characteristics could eventually be recognised from aerial images, Street View, drone images or 3D scans. The AI would identify the visible roof characteristics, the morphological overview would structure this variation, and prefab companies could use the results to select a suitable DÂK product, adaptable module or new roof family.

## 4.7 Defined DÂK 1.0 prefab roof profile

The morphological roof overview can also be used to define DÂK 1.0 as the first prefab roof profile within MEER. This creates a reference profile for the results chapter, where the analysed roofs are compared with the visible characteristics of the DÂK 1.0 direction.

DÂK 1.0 focuses on pitched roofs of terraced and corner dwellings, mainly from the post-war housing stock. The concept is aimed at roofs where the existing purlin or rafter structure and roof boarding can remain in place, while the roof covering and insulation are replaced. The system also includes basic details for junctions and feedthroughs and can be combined with 8 or 16 solar panels and an optional compact 4 kW hybrid heat pump.

Table 4. Defined DÂK 1.0 prefab roof profile

| Morphological category     | DÂK 1.0 prefab roof profile                                  |
|----------------------------|--------------------------------------------------------------|
| House type                 | Terraced houses and corner houses                            |
| Roof type                  | Gable roof                                                   |
| Roof construction          | Existing purlin or rafter structure retained                 |
| Roof surface               | Average sloping roof surface around 50 m <sup>2</sup>        |
| Roof covering              | Existing roof tiles replaced                                 |
| Penetrations and junctions | Basic details for junctions and feed-throughs                |
| Installations on roof      | 8 or 16 solar panels, optional compact 4 kW hybrid heat pump |

The DÂK 1.0 profile used in this research is based on the MEER application and is summarised in Table 4.

This chapter answers SQ1 and SQ2. The relevant characteristics for prefab roof renovation are context, roof properties and additions, because these determine project organisation, element design and the need for adaptable details. These characteristics were structured into the morphological roof overview so that each roof can be described and compared in the same way.

## 5 Results of the MEER roof analysis

This chapter applies the morphological overview to the MEER dataset. The results show which roof characteristics support the DÂK 1.0 standard direction and which characteristics require adaptability.

### 5.1 Dataset and interpretation

The morphological roof overview was applied to 1.480 roofs from dwellings involved in the MEER project. The dataset is relevant for the DÂK context, but it should not be interpreted as representative of the full Dutch housing stock. The results therefore describe the roof variation within this specific MEER dataset and are used to assess the first DÂK 1.0 product design.

The analysis is mainly based on visible roof characteristics from aerial imagery, Street View and QGIS data. Characteristics such as house type, roof type, roof surface, roof covering, silhouette and visible roof additions could often be identified. Hidden or technical characteristics, such as roof construction, structural condition and existing insulation, could not be verified from the dataset. These remain necessary technical checks before implementation.

For the comparison with DÂK 1.0, only the defined DÂK 1.0 profile in paragraph 4.7 was used as reference. This means that the fit was based on terraced or corner dwellings, pitched gable roofs, existing roof tiles and an average sloping roof surface around 50 m<sup>2</sup>. Roof construction is part of the DÂK 1.0 profile, but was not included in the quantitative fit because it could not be verified from the dataset.

### 5.2 Fit with the DÂK 1.0 prefab roof

Based on the selected fit criteria, the analysed MEER dwellings show a strong overlap with the DÂK 1.0 direction, as summarised in Table 5. Most dwellings match the main prefab roof profile: terraced or corner dwellings with tiled gable roofs. This means that the dataset already contains a large share of roofs that are relevant for the first DÂK 1.0 product design.

A total of 1.364 dwellings, or 92.2% of the dataset, fit the main DÂK 1.0 direction based on house type, roof type and roof covering. Within this group, 304 dwellings also have a roof surface between 40 and 60 m<sup>2</sup> and therefore fit the defined DÂK 1.0 profile most directly. These dwellings form a possible first selection for further technical verification before pilot implementation.

The remaining 1,060 dwellings still fit the main DÂK 1.0 direction, but need adaptation because the roof surface is larger, smaller or requires further verification. These roofs do not require a completely new roof concept, but they do require dimensional variants, adaptable segmentation or further technical checks. Only 116 dwellings, or 7.8% of the dataset, fall outside the current DÂK 1.0 direction.

The fit groups should not be interpreted as a final GO/NOGO classification. They show the visible degree of deviation from the current DÂK 1.0 direction and are intended to support interpretation, prioritisation and further technical verification

*Table 5. Fit of the MEER dataset with the DÂK 1.0 prefab roof profile*

| Variation group                       | Number | Share | Meaning for interpretation                                                                                      |
|---------------------------------------|--------|-------|-----------------------------------------------------------------------------------------------------------------|
| Close to DÂK 1.0 profile              | 304    | 20.5% | Smallest visible deviation; useful for pilots and technical verification.                                       |
| Same direction with adaptation points | 1.060  | 71.6% | Same roof family, but visible variation in dimensions, pitch or additions. Main input for variants and modules. |
| Outside current DÂK 1.0 logic         | 116    | 7.8%  | Large deviation; input for later roof families or new design directions.                                        |

### 5.3 Dominant parameters for standardisation

Several parameters occur frequently within the MEER dataset and are therefore interpreted as relevant for standardisation within the DÂK 1.0 context, as shown in Table 6. Almost all dwellings are terraced or corner dwellings, most roofs are gable roofs, and most roofs have roof tiles. These characteristics directly align with the DÂK 1.0 prefab roof profile.

*Table 6. Dominant parameters supporting standardisation*

| Parameter              | Dominant result             | Count / filled values |
|------------------------|-----------------------------|-----------------------|
| House type             | Terraced or corner dwelling | 1,475 / 1,479 (99.7%) |
| Roof type              | Gable roof                  | 1,399 / 1,440 (97.2%) |
| Roof covering          | Tiled roof covering         | 1,396 / 1,423 (98.1%) |
| Roof covering type     | Concrete roof tile          | 1,275 / 1,423 (89.6%) |
| Silhouette             | Symmetrical                 | 1,178 / 1,427 (82.6%) |
| Neighbourhood location | Suburban / village          | 1,299 / 1,468 (88.5%) |

These results show that the dataset does not consist of completely unique roof situations. A clear standard direction can be identified: terraced and corner dwellings with tiled gable roofs. This supports DÂK 1.0 as a logical first prefab roof family.

### 5.4 Parameters requiring adaptability

Although the main DÂK 1.0 direction fits the dataset well, several parameters still require adaptability. These parameters do not always exclude a roof from DÂK 1.0, but they show where modules, variants or technical checks are needed.

Roof surface is the main adaptability parameter. DÂK 1.0 is defined around a sloping roof surface of approximately 50 m<sup>2</sup>, while the dataset has an average of 65.6 m<sup>2</sup>. Only 304 dwellings fall within the practical 40-60 m<sup>2</sup> range. This means that many roofs fit the same DÂK 1.0 logic, but require larger dimensions, adaptable segmentation or additional element variants.

Silhouette is also important for standardisation, as shown in Table 7. A symmetrical roof is easier to repeat because both roof planes have the same geometry. In the interpretation used in this research, asymmetrical roofs are treated as requiring additional attention because differences between roof planes can influence element dimensions, ridge details, eaves details, lifting logic and installation sequence.

Table 7. Silhouette distribution and meaning for prefab adaptation

| Silhouette   | Number of dwellings | Share of dataset | Meaning                                          |
|--------------|---------------------|------------------|--------------------------------------------------|
| Symmetrical  | 1,178               | 79.6%            | Strong basis for repeated prefab elements        |
| Asymmetrical | 249                 | 16.8%            | Requires adapted geometry or left/right variants |
| Unknown      | 53                  | 3.6%             | Requires further verification                    |

Within the broader DÂK 1.0 direction, 234 dwellings have an asymmetrical silhouette. This means that 17.2% of the roofs that otherwise fit the main DÂK 1.0 direction still need extra attention because of geometry. These roofs should not automatically be excluded, but they are less suitable for one fixed standard element strategy.

Roof penetrations and visible additions are also important for adaptability. DÂK 1.0 already includes basic details for junctions and feed-throughs, and the dataset shows why this is needed. In the full dataset, 1,266 dwellings have at least one recorded roof penetration (85.5%). Within the broader DÂK 1.0 direction, this is 1,212 dwellings (88.9%). Table 8 summarises these additions. Because roof penetrations were recorded frequently, they should be treated as recurring design conditions within the DÂK 1.0 product-family logic, rather than as rare exceptions.

Table 8. Roof penetrations and additions in the full dataset and DÂK 1.0 direction

| Roof penetration / addition            | Full dataset | Share of dataset | Within DÂK 1.0 direction | Share within DÂK 1.0 direction |
|----------------------------------------|--------------|------------------|--------------------------|--------------------------------|
| Flue gas outlet                        | 1,083        | 73.2%            | 1,045                    | 76.6%                          |
| Sewer vent                             | 998          | 67.4%            | 962                      | 70.5%                          |
| Chimney                                | 524          | 35.4%            | 479                      | 35.1%                          |
| Ventilation                            | 166          | 11.2%            | 165                      | 12.1%                          |
| At least one recorded roof penetration | 1,266        | 85.5%            | 1,212                    | 88.9%                          |

Roof windows and solar panels are also common. In the full dataset, 1,073 dwellings have at least one roof window (72.5%) and 607 dwellings have solar panels (41.0%). Within the broader DÂK 1.0 direction, this is similar: 1,031 dwellings have roof windows (75.6%) and 576 dwellings have solar panels (42.2%). This means that both should be treated as recurring modules, not as exceptions.

These additions do not mean that the roofs need a new design direction. They show that the standard roof surface is often interrupted. DÂK 1.0 should therefore include standard solutions for recurring penetrations, roof windows, solar panels and roof-edge details.

## 6 Broader application to prefab roof renovation

This chapter translates the dataset results into practical meaning for prefab roof companies. The focus shifts from describing roof variation to using that variation for product-family decisions.

### 6.1 Meaning for prefab roof companies

For prefab roof companies, the overview can be used during the intake phase to separate roofs into three groups: roofs that fit the DÂK 1.0 base profile, roofs that need dimensional or module-based adaptation, and roofs that require a different design direction. This makes the analysis actionable, while still making clear that visual classification does not replace technical engineering.

The MEER analysis shows that the dwellings involved in the project are well selected for the DÂK 1.0 prefab roof direction. The dominant group consists of terraced and corner dwellings with tiled gable roofs. This group contains 1,364 dwellings, or 92.2% of the MEER dataset, which means prefab roof companies can start from a clear and repeated roof type instead of the full complexity of the housing stock.

DÂK 1.0 should therefore not be developed as one fixed roof product, but as the first product family. The standard base is formed by tiled gable roofs, while the adaptable part should respond to roof surface, silhouette and roof additions. This includes dimensional variants, adapted geometry for asymmetrical roofs, standard feed-through

details, modules for roof windows and solar panels, and adaptable roof-edge details. In this way, roofs that do not fit the first standard profile directly can still be renovated without becoming fully custom projects.

## 6.2 Basis for a modular roof architecture

The morphological roof overview does not yet form a complete modular roof architecture, because it does not define final technical modules, connection details or interface rules. However, it provides the classification basis from which such an architecture can be developed. By structuring roof variation into context, roof properties and additions, the overview shows which characteristics can support a standard prefab base and which characteristics require adaptable modules, variants or technical checks.

In this way, the overview helps translate existing roof variation into product-family logic. Recurring characteristics, such as tiled gable roofs of terraced and corner dwellings, can form the basis of a standard roof family. Frequently occurring deviations, such as larger roof surfaces, asymmetrical silhouettes, roof windows, penetrations and solar panels, can be interpreted as input for adaptable modules or predefined variants. Less frequent or more complex roof situations may require future roof families.

The morphological roof overview should therefore be seen as a step between roof analysis and modular system development. It makes the variation visible and comparable before technical design decisions are made. A future modular roof architecture can build on this structure by defining standard components, adaptable modules, interface rules and decision logic for different roof families.

## 6.3 From MEER dataset to national upscaling

The results of this research only describe the dwellings involved in the MEER project. These dwellings are a strong starting point for testing DÂK 1.0, because most of them fit the main prefab roof direction well. However, this does not mean that DÂK 1.0 is automatically suitable for the full Dutch housing stock.

To accomplish the goal of renovating a large part of the Dutch housing stock, the analysis must be expanded beyond the selected MEER project dwellings. A large number of dwellings still need to be renovated, and the variation in the full housing stock is broader than in the MEER dataset. It is likely that broader housing-stock datasets will include a wider range of roof types, dimensions, roof coverings, additions and ownership situations than the selected MEER dataset. This wider variation first needs to be mapped before it can be translated into scalable prefab solutions.

A logical next step is to apply the morphological roof overview to larger housing-stock datasets, supported by AI recognition. AI could help identify roof type, roof surface, silhouette, roof covering, additions and installations from aerial images, Street View, drone images or 3D scans. The morphological overview can then structure this information and translate it into standard roof profiles, adaptable modules and new product families.

DÂK 1.0 should therefore be seen as the first product family, not as the final solution for all roofs. The MEER dwellings provide a suitable test group for prefab roof renovation, while a wider housing-stock analysis is needed to develop additional product families for other roof types and more complex situations. In this way, the approach can grow from one promising prefab roof concept towards a broader library of prefab roof solutions for large-scale renovation.

## 6.4 Impact on engineering, production and installation

For engineering, the results may reduce uncertainty at the start of a project by making recurring roof characteristics visible before detailed technical checks. Because the main roof type is repeated across most MEER dwellings, prefab companies can develop standard assumptions, standard details and clear decision rules. Engineering effort can then focus on recurring adaptations instead of redesigning every roof from the beginning.

For production, the results provide input for a more repeatable manufacturing strategy, because they identify which roof characteristics recur often enough to be considered in a standard base, dimensional variants or modules. The standard base can be produced around tiled gable roofs, while dimensional variants and modules make it possible to cover the larger adaptation group. This does not mean that every roof element is identical, but it does reduce uncontrolled variation.

For installation, the results can inform preparation and planning by identifying recurring additions, such as penetrations, roof windows and solar panels, that should be considered before on-site work starts. Similar roof types make it easier to prepare lifting methods, transport, installation sequence and work instructions. Roof

additions such as penetrations, roof windows and solar panels should already be included in this preparation, because they occur frequently and are not exceptions.

## 7 Discussion

This chapter reflects on what the results mean, how reliable the method is and how far the findings can be applied beyond the MEER dataset.

### 7.1 Interpretation of the findings

Within the boundaries of the selected fit criteria, the MEER project dwellings form a strong starting point for testing the DÂK 1.0 direction. Most dwellings follow the same main roof logic: terraced or corner dwellings with tiled gable roofs. This supports the choice to start prefab roof renovation with this roof type.

However, the results also show that standardisation cannot mean one fixed product for every roof. Even within this well-selected dataset, variation remains in roof surface, silhouette, penetrations, roof windows, solar panels and roof-edge details. DÂK 1.0 should therefore be understood as the first product-family direction: a standard base with adaptable variants and modules.

A different categorisation could have changed the emphasis of the results. For example, a mainly technical categorisation would have focused more on roof geometry and engineering constraints, while a mainly contextual categorisation would have emphasised ownership and project organisation. However, the main conclusion would probably remain that prefab roof renovation needs both a standard base and adaptable modules, because variation occurs in both roof properties and additions.

### 7.2 Standardisation versus custom renovation

Stakeholder discussions and project feedback indicate that prefab roof renovation is often approached with caution because existing roofs are perceived as highly variable. The MEER analysis shows that, within this dataset, several important roof characteristics recur frequently.

The morphological overview helps make this shift possible. It separates the characteristics that support a standard base from the characteristics that require adaptation. In this way, variation becomes input for product families and standard details, instead of a reason to redesign every project from the beginning.

Expert feedback confirmed that the practical value of the overview lies especially in making deviations visible and comparable. This makes the result less black-and-white than a GO/NOGO model and gives different stakeholders a shared basis for their own interpretation of renovation potential.

### 7.3 Reliability and limitations

The analysis is suitable for early selection, clustering and product strategy, but not for final engineering approval. This is because the method is mainly based on visible and spatial data from aerial imagery, Google Street View and QGIS. These sources are useful for recognising and comparing roof characteristics such as roof type, roof covering, silhouette and visible additions. This fits the role of morphological and GIS-based analysis as a way to structure and compare building information (Leupen & Mooij, n.d.).

However, final roof renovation decisions also depend on technical performance requirements that cannot be verified through visual analysis alone. Jellema 4A shows that roofs must be assessed on aspects such as mechanical performance, building physics, water- and wind-tightness, construction, insulation, roof penetrations and detailing (Hofkes et al., 2005). These aspects require technical verification through drawings, scans, housing association data or site inspection. This limitation was also confirmed in the expert and stakeholder interviews, where the overview was recognised as useful for early clustering and discussion, but not as a replacement for final engineering checks.

### 7.4 Representativeness and wider application

The quantitative results are specific to the dwellings involved in the MEER project. The dataset is not representative of the full Dutch housing stock, because the dwellings are already relevant for the DÂK approach. This explains the strong fit with DÂK 1.0.

This limits the generalisability of the quantitative findings, but not necessarily the transferability of the framework. The framework can be tested on broader datasets in future research. For MEER, the dataset is a suitable test group. For national upscaling, however, the morphological overview should be applied to larger and more varied housing-stock datasets. This will make it possible to identify other roof types and develop additional product families beyond DÂK 1.0.

## 7.5 Usability and scientific value

The usable value of this research is that it translates roof variation into usable product logic for prefabricated roof companies. It shows where DÂK 1.0 can start, which roofs need adaptation and which roofs require a different design direction.

The methodological contribution of this research lies in the structured categorisation of roof variation for prefabricated renovation decision-making. The practical contribution lies in translating visible roof variation into early product-family logic for prefabricated roof companies. The morphological overview provides fixed categories to describe and compare roof characteristics. This makes the method suitable for future AI-supported roof recognition, where recognised roof characteristics can be translated into standard profiles, modules and product families.

# 8 Conclusion

This research answered the question of how existing roof variation can be systematically categorised and analysed to support standardisation and adaptability in scalable prefabricated biobased roof renovation. The result is a morphological roof overview structured around context, roof properties and additions. This structure makes roof variation visible, comparable and usable for prefabricated decision-making.

Applied to 1,480 roofs in the MEER dataset, the overview shows that the selected dwellings fit DÂK 1.0 well. Most dwellings are terraced or corner houses with tiled gable roofs: 1,364 dwellings, or 92.2% of the dataset. This makes the MEER dwellings a strong starting point for testing DÂK 1.0. Within this group, 304 dwellings fit the defined DÂK 1.0 profile most directly. The other 1,060 dwellings follow the same product logic, but need adaptation in roof size, segmentation or detailing.

The main conclusion is that DÂK 1.0 should be developed as the first product family, not as one fixed roof product. The standard base can be formed by tiled gable roofs, while recurring variation such as roof surface, asymmetrical silhouettes, penetrations, roof windows, solar panels and roof-edge details should be translated into variants, modules and technical checks.

The results are specific to the dwellings involved in the MEER project and cannot automatically be generalised to the full Dutch housing stock. To accomplish the goal of renovating a large part of the Dutch housing stock, the same method should be applied to broader datasets. AI-supported roof recognition could help scale this process in future work, provided that recognition accuracy is validated against reliable reference data.

Overall, the morphological roof overview provides a strong basis to shift from project-specific renovation towards a more structured prefabricated renovation approach. It helps prefabricated roof companies decide where DÂK 1.0 can start, where adaptability is needed, and where future roof families should be developed.

## 9 Future vision

The previous chapters describe and interpret the current research. This chapter outlines possible next steps for using the same structure in future applications.

The following directions are not validated outcomes of this research, but possible next steps based on the structure and limitations of the morphological overview.

### 9.1 AI-supported roof recognition

The morphological roof overview can form the basis for AI-supported roof recognition. Because the overview uses fixed categories, roof characteristics such as roof type, silhouette, roof surface, roof covering, additions and installations can eventually be recognised from aerial images, Street View, drone images or 3D scans. The recognised data can then be structured through the morphological overview and used to match roofs with a suitable prefab solution.

### 9.2 Roof type library

A next step is to develop a roof type library linked to prefab product families. DÂK 1.0 can be the first product family in this library, focused on tiled gable roofs. Other roof types can later be added as new product families. Each roof type should include standard dimensions, common variations, suitable modules, required technical checks and product-family logic. This would make the method more directly usable for prefab roof companies.

### 9.3 Extension to whole-house renovation

The same method can also be expanded beyond roofs. Façades, floors, extensions and installations can be structured in a similar way. This would make it possible to move from a roof-focused analysis towards a broader whole-house method for industrialised renovation. In this way, the morphological approach can support not only prefab roof renovation, but also the wider transition towards scalable housing renovation.

# 10 References

- Bonnema, G. M. (2016). *Systems design and engineering: Facilitating multidisciplinary development projects*. CRC Press.
- Building Balance. (2025). *MEER application Building Balance*.
- Centraal Bureau voor de Statistiek. (2023, December). *Energieverbruik woningen; woningtype, oppervlakte, bouwjaar en bewoning*. <https://opendata.cbs.nl/#/CBS/nl/dataset/85140NED/table?dl=A752C>
- Centraal Bureau voor de Statistiek. (2025, December 8). *1946 Woningnood en wederopbouw*. <https://www.cbs.nl/nl-nl/longread/diversen/2025/tijdslijn-woningvoorraad/1946-woningnood-en-wederopbouw>
- Design Council. (2005). *The Double Diamond*. <https://www.designcouncil.org.uk/our-resources/the-double-diamond/>
- Europees Parlement. (2023, December 7). *De EU en het Klimaatakkoord van Parijs: Het streven naar klimaatneutraliteit*.
- Hofkes, K., Zimmermann, N., Van Tol, A., Flapper, H. A. J., Bonebakker, M., Brinksma, H., Van Den Hout, A. F., Maessen, W. H., Quist, P. G., Quist, W. J., & Salden, M. W. R. (2005). *Jellema 4A: Omhulling: Prestatie-eisen/daken* (2nd ed., 1st printing). ThiemeMeulenhoff. <https://www.thiememeulenhoff.nl>
- Hofkes, K., Van Tol, A., Bonebakker, M., Flapper, H. A. J., Brinksma, H., Zimmermann, N., Te Boveldt, A., & Bakker, H. E. (2004). *Jellema 7: Bouwmethode II* (2nd ed., 2nd printing). ThiemeMeulenhoff.
- Hofkes, K., Brinksma, H., Van Tol, A., Bonebakker, M., Flapper, H. A. J., Zimmermann, N., Rentier, C., Reymers, J., & Salden, M. W. R. (2005). *Jellema 4B: Omhulling: Gevels II*. ThiemeMeulenhoff.
- Lahfaji, [Initials missing], et al. (2024). *Complexity in construction projects: A literature review*. ResearchGate. [https://www.researchgate.net/publication/378705676\\_Complexity\\_in\\_Construction\\_Projects\\_A\\_Literature\\_Review](https://www.researchgate.net/publication/378705676_Complexity_in_Construction_Projects_A_Literature_Review)
- Leupen, B., & Mooij, H. (n.d.). *Housing design: A manual*. NAI Publishers.
- Ministerie van Algemene Zaken. (2019, April). *Klimaatakkoord*. <https://www.rijksoverheid.nl/onderwerpen/klimaatverandering/documenten/rapporten/2019/06/28/klimaatakkoord>
- Nieuwenhuis, K. (2026, June 12). *Wat zijn de voor- en nadelen van prefab gevelelementen?* Leebo. <https://leebo.nl/kennisbank/wat-zijn-de-voor-en-nadelen-van-prefab-gevelelementen/>
- Petersen, M. (2025). *Standaardisatie in variatie: Onderzoek naar de karakteristieken van grondgebonden rijwoningen*. Hogeschool Utrecht, Lectoraat Nieuwe Energie in de Stad.
- Solvari. (2025, June 19). *Dakpannen: Soorten + prijs*. Mijn Dakdekker. <https://www.mijn-dakdekker.nl/dakbedekking/dakpannen>
- Stroomversnelling. (2020, June). *Marktmonitor Nul-op-de-meter*. <https://stroomversnelling.nl/nieuws-bericht/aantal-nul-op-de-meter-woningen-blijft-stijgen-sociale-huursector-loopt-voorop/>
- ThiemeMeulenhoff. (2005). *Jellema 4B: Omhulling: Gevels II*. ThiemeMeulenhoff.
- TNO. (z.d.). *Prefabricated construction: accelerating sustainable housing construction*. <https://www.tno.nl/en/sustainable/circular-industrial-construction/industrial-construction/prefab/>
- Tseng, M. M., Wang, Y., & Jiao, R. J. (2017). Mass customization. In L. Laperrière & G. Reinhart (Eds.), *CIRP encyclopedia of production engineering*. Springer. [https://doi.org/10.1007/978-3-642-35950-7\\_16701-3](https://doi.org/10.1007/978-3-642-35950-7_16701-3)
- Van Boeijen, A., Daalhuizen, J. J., Van der Schoor, R., & Zijlstra, J. (2013). *Delft Design Guide: Design strategies and methods*. BIS Publishers.
- Van Elk, R. S. F. J., & Priemus, H. (1971). *Niet-traditionele woningbouwmethoden in Nederland* (2nd ed.). Samson Uitgeverij NV.

Walraven, T. (2024). *Towards data-driven renovations: An exploratory study on the automation of façade quickscans using computer vision*. Hogeschool Utrecht.

Woningonderzoek Nederland. (2024). *Datawonen*. <https://datawonen.nl/>

# 11 Appendices

## 11.1 Explanation of categories

### 11.1.1 Context

#### *House Type*

##### **General definition:**

The house type describes the positioning of a dwelling within a housing block or urban context. This positioning influences the roof shape, connection details, and the possibilities for serial renovation.

##### **1.1.1 Terraced House:**

A dwelling that is connected to other dwellings on both sides, where the roof is structurally connected to adjacent roofs.

##### **1.1.2 Corner House:**

The end dwelling of a row of houses where only one side is structurally connected to an adjacent dwelling.

##### **1.1.3 Detached House:**

A dwelling without adjacent roofs.

A dwelling without direct structural connections to surrounding houses.

##### **1.1.4 Other:**

All other dwelling types that do not fall within the categories above.

##### **Relevance for prefab roof analysis:**

The house type determines the lateral roof connections and the extent to which dwellings share structural components. In connected dwellings, prefab solutions can often be applied serially, whereas detached houses more frequently require customization. In addition, the house type influences logistics, repetition, and scalability of renovation projects (ThiemeMeulenhoff et al., 2004; interviews with Rick Ebberts and Rogier Lateveer, 2026).

#### *Province*

##### **General definition:**

The province describes the geographical region in which the dwelling is located. This regional location may influence building traditions, housing typologies, and applied roof constructions.

##### **Relevance for prefab roof analysis:**

The province makes it possible to analyze regional patterns in housing typologies and roof constructions. This allows investigation into whether certain roof shapes, constructions, or renovation approaches occur more frequently in specific regions. This clustering supports the development of standardized prefab roof solutions on a regional scale (MEER Application Building Balance, 2025; interviews with Rick Ebberts and Rogier Lateveer, 2026).

#### *Ownership*

##### **General definition:**

The ownership category describes the ownership situation of dwellings within a housing block or street. This ownership situation influences the organizational feasibility of serial renovation projects.

**1.3.1 Continuous Ownership:**

A situation in which an entire housing block or row of houses is owned by a single owner, usually a housing corporation.

**1.3.2 Mixed Ownership:**

A situation in which housing corporation properties and privately owned homes are mixed within the same housing block.

**Relevance for prefab roof analysis:**

The ownership situation directly affects the scalability of prefab renovations. With continuous ownership, entire housing blocks can be renovated simultaneously, allowing standardization and industrial prefabrication to be efficiently applied. In mixed ownership situations, more complex connection details and organizational limitations often arise because not all residents participate in the renovation (interviews with Rick Ebberts, 2026).

*Orientation***General definition:**

The orientation describes the position of the roof relative to north, expressed in degrees. This orientation determines the direction of the roof surfaces within the environment.

**1.4.1 Orientation in Degrees:**

The angle of the ridge or roof surface relative to north, measured in degrees.

**Relevance:**

The orientation of a roof influences the solar exposure of the roof surface and thereby its suitability for installations such as solar panels. In addition, the orientation can affect daylight penetration (interviews with Rick Ebberts and Rogier Lateveer, 2026).

*Neighborhood Type***General definition:**

The neighborhood type describes the urban structure and accessibility of the residential environment in which the dwelling is located.

**1.5.1 Urban Building Block:**

Densely built urban structure with enclosed building blocks and limited public space.

**1.5.2 Post-War Residential Area:**

Spacious residential area with mainly terraced houses and relatively wide streets.

**1.5.3 Garden City Low-Rise:**

Residential area with open building structures, extensive green spaces, and low-rise buildings.

**1.5.4 Cul-de-sac Neighborhood:**

Residential area with winding roads, shared residential streets, and an organic parcel structure.

**1.5.5 Other:**

All other neighborhood structures that do not fall within the categories above.

**Relevance:**

The neighborhood type influences the logistical accessibility of dwellings during renovation projects. Factors such as street width, parking space, and accessibility determine the extent to which prefab roof elements can be transported and installed efficiently. As a result, the neighborhood type directly affects feasibility, crane positioning, and construction logistics (Climate Adaptation Services; interviews with Rogier Lateveer, 2026).

*Neighborhood Location***General definition:**

The neighborhood location describes the position of a residential area relative to the urban center.

**1.6.1 City Center:**

Dwellings located in a highly urbanized environment with a compact building structure.

**1.6.2 Suburban/Village:**

Dwellings located on the edge of urban areas or within village centers.

**1.6.3 Rural:**

Dwellings located outside urban areas in a rural environment.

**Relevance:**

The location of a neighborhood affects accessibility, transportation possibilities, and available space for construction logistics. Inner-city locations often impose limitations on transportation and lifting operations, whereas rural locations generally provide more space for prefab installation and storage (interviews with Rogier Lateveer and Rick Ebbers, 2026).

## 11.1.2 Roof properties

*Roof Type***General definition:**

The roof type describes the overall geometric main form of the roof.

**2.1.1 Gable Roof:**

A roof shape consisting of two sloping roof surfaces that meet at a central ridge.

**2.1.2 Hip Roof:**

A roof shape in which all sides slope downward toward the façades.

**2.1.3 Mansard Roof:**

The roof type forms one of the most important parameters within the morphological analysis of roofs.

**2.1.4 Shed Roof:**

A roof shape consisting of one sloping roof surface without a central ridge.

**2.1.5 Flat Roof:**

A roof shape with minimal slope in which the roof surface is nearly horizontal.

**Relevance:**

The roof type forms one of the most important parameters within the morphological analysis of roofs. The main shape of the roof determines the geometry, structural build-up, drainage, and segmentation of prefab roof elements. As a result, the roof type directly influences standardization, module dimensions, and manufacturability of prefab solutions (Hofkes et al., 2005; interview with Rick Ebbers, 2026).

*Silhouette/Cross-section***General definition:**

The silhouette describes the two-dimensional cross-section of the roof and dwelling.

**2.2.1 Symmetrical Profile (Classic Silhouette):**

A profile in which both roof surfaces have the same pitch angle and dimensions.

### **2.2.2 Asymmetrical Profile:**

A profile in which the roof surfaces differ in length or pitch angle.

### **2.2.3 Stepped Profile (Roof with Stepped Ridge):**

A profile in which sections of the roof are located at different heights.

### **2.2.4 Single-Sided Sloping Profile (Shed Roof Silhouette):**

A profile consisting of one sloping roof surface.

#### **Relevance:**

The silhouette determines the exact geometric configuration of the roof and thereby directly influences the dimensions, segmentation, and connections of prefab roof elements. Variations in the silhouette may lead to additional customization in production and assembly (ThiemeMeulenhoff et al., 2004; Petersen, 2025; interviews with Rogier Lateveer, 2026).

#### *Roof Structure*

##### **General definition:**

The roof structure describes the load-bearing system on which the roof is constructed.

##### **2.3.1 Purlin Roof:**

A structural system in which horizontal purlins transfer roof loads to load-bearing walls.

##### **2.3.2 Rafter Roof:**

A structural system in which inclined rafters run directly from ridge to wall.

#### **Relevance:**

The roof structure determines how prefab roof elements can be attached and what load-bearing capacity is available. In addition, the structure influences the extent to which existing components can be retained or replaced during renovation projects (Hofkes et al., 2005; interviews with Rick Ebbers and Rogier Lateveer, 2026).

#### *Roof Surface Area*

##### **General definition:**

The roof surface area describes the total area of the roof surface, expressed in square meters.

#### **Relevance:**

The roof surface area directly affects the dimensions, weight, and segmentation of prefab roof elements. Larger roof areas often require multiple modules, additional structural provisions, and adapted logistical solutions for transportation and installation. Furthermore, the surface area influences material quantities and production costs of prefab renovations (Hofkes et al., 2005; interviews with Rick Ebbers and Rogier Lateveer, 2026).

#### *Roof Height (m)*

##### **General definition:**

The roof height describes the vertical distance between ground level and the highest point of the roof.

##### **Relevance for prefab roof analysis:**

The roof height affects accessibility during renovation projects and partly determines which lifting and assembly provisions are required for prefab installation. Taller buildings often require heavier equipment, additional safety measures, and adapted logistical planning (interview with Rick Ebbers, 2026).

#### *Span Width (m)*

##### **General definition:**

The span width describes the width of the dwelling perpendicular to the ridge direction.

**Relevance for prefab roof analysis:**

The span width determines the span of the roof and thereby directly affects the dimensions, structural behavior, and module division of prefab roof elements. Larger spans may require additional structural reinforcements within the prefab system (Jellema 4A; interview with Rick Ebberts, 2026).

*Roof Pitch (degrees)*

**General definition:**

The roof pitch describes the angle of the roof surface relative to the horizontal plane, expressed in degrees.

**Relevance for prefab roof analysis:**

The roof pitch strongly influences the geometry, drainage, and attachment method of prefab roof elements. In addition, the pitch angle determines which roof coverings are technically applicable and which forms of standardization are possible within prefab production systems. By clustering roof pitches, common configurations can be identified for serial production (Hofkes et al., 2005; interview with Rick Ebberts, 2026).

*Existing Insulation*

**General definition:**

The existing insulation describes the position of the insulation layer within the current roof build-up.

**2.8.1 Internal Insulation:**

The insulation layer is located on the inside of the roof structure.

**2.8.2 External Insulation:**

The insulation layer is located on the outside of the roof structure, beneath the roof covering.

**Relevance:**

The position of the existing insulation influences the construction sequence, detailing, and connection of new prefab roof elements. In addition, this parameter determines to what extent existing roof layers can remain in place during renovation (interview with Rogier Lateveer, 2026).

*Roof Covering*

**General definition:**

Roof covering describes the outer protective layer of the roof.

**2.9.1 Ceramic Roof Tile:**

Roof covering consisting of baked clay roof tiles.

**2.9.2 Concrete Roof Tile:**

Roof covering consisting of concrete roof tiles.

**2.9.3 Thatched Roof:**

Natural roof covering made of bundles of thatch.

**2.9.4 Slate Roofing:**

Roof covering made of natural stone or fiber cement slates.

**2.9.5 Bitumen:**

Waterproof roof covering based on bituminous layers, mainly applied on flat roofs.

**Relevance:**

The roof covering influences the weight, detailing, attachment method, and waterproofing of prefab roof elements. In addition, the type of roof covering partly determines which renovation strategies and prefab connection details are applicable (Hofkes et al., 2005; interview with Rick Ebbers, 2026).

### *Rainwater Drainage*

#### **General definition:**

Rainwater drainage describes the method by which rainwater is discharged from the roof to the sewer or infiltration system.

#### **2.10.1 Half-Round Gutter in Brackets:**

A gutter system in which the gutter is visibly attached to the roof edge with gutter brackets.

#### **2.10.2 Box Gutter in Brackets:**

A rectangular roof gutter visibly attached to the roof edge.

#### **2.10.3 Gutter Corbels:**

A roof gutter construction in which wooden or structural corbels support the gutter.

#### **2.10.4 Enclosed Gutter:**

A roof gutter concealed behind cladding or façade finishing.

#### **Relevance for prefab roof analysis:**

Rainwater drainage determines important connection details at the roof edge of prefab roof elements. Variations in gutters and drainage systems influence detailing, waterproofing, and installation of prefab roofs. In addition, existing gutters influence the dimensions and connection of new roof elements to the façade (Hofkes et al., 2005; interviews with Rick Ebbers and Rogier Lateveer, 2026).

## 11.1.3 Additions

### *Penetrations*

#### **General definition:**

Penetrations include all elements that physically pass through the roof surface and thereby interrupt the roof plane.

#### **3.1.1 Flue Gas Exhaust:**

A penetration for the discharge of flue gases from heating installations.

#### **3.1.2 Chimney:**

A masonry structure for the discharge of smoke from a fireplace or combustion appliance.

#### **3.1.3 Ventilation:**

A penetration for ventilation ducts or air supply and exhaust systems.

#### **3.1.4 Cable Penetration:**

A smaller penetration for electrical cabling or installation technology.

#### **3.1.5 Sewer Vent Pipe:**

A vent pipe connected to the dwelling's sewer system.

#### **3.1.6 No Penetrations:**

A roof surface without interruptions or technical penetrations.

#### **Relevance for prefab roof analysis:**

Penetrations interrupt the standard build-up of prefab roof elements and require specific openings, waterproof connections, and installation details. The position and quantity of penetrations strongly determine the degree of standardization possible within prefab renovation (Hofkes et al., 2005; interviews with Rick Ebbers and Rogier Lateveer, 2026).

### *Roof Window*

#### **General definition:**

A roof window is an opening in the roof surface intended for daylight access and ventilation.

#### **3.2.1 No Roof Window:**

A roof surface without roof windows.

#### **3.2.2 Roof Window on Front or Rear Side:**

A roof window positioned on the front or rear side of the dwelling.

#### **3.2.3 Number of Roof Windows:**

The number of roof windows present within the roof surface.

#### **Relevance for prefab roof analysis:**

Roof windows influence the geometry and segmentation of prefab roof elements because they require openings and additional structural provisions. The position and quantity of roof windows determine the extent to which roof elements can be standardized without additional customization (Hofkes et al., 2005; Petersen, 2025; interviews with Rogier Lateveer, 2026).

### *Dormer*

#### **General definition:**

A dormer is an extension within the roof surface that creates additional space and daylight within the dwelling.

#### **3.3.1 No Dormer:**

A roof surface without dormers.

#### **3.3.2 Dormer in the Middle of the Roof:**

A dormer freely positioned within the roof surface.

#### **3.3.3 Dormer Aligned with the Façade:**

A dormer aligned with the underlying façade.

#### **3.3.4 Dormer Against the Side Wall:**

A dormer positioned directly against a side façade or partition wall.

#### **3.3.5 Dormer Against the Ridge:**

A dormer positioned high in the roof surface against the ridge line.

#### **3.3.6 Dormer Against Neighboring Property:**

A dormer positioned directly against the dwelling separation wall.

#### **3.3.7 Number of Dormers:**

The number of dormers present within the roof surface.

#### **Relevance for prefab roof analysis:**

Dormers strongly influence the geometry, segmentation, and dimensions of prefab roof elements. Due to variation in position, dimensions, and configuration, additional complexity often arises in design and production. Dormers therefore largely determine whether a prefab roof can be executed in a standardized manner or whether adaptive

customization is required (Hofkes et al., 2005; MEER Application Building Balance, 2025; Petersen, 2025; interviews with Rick Ebberts and Rogier Lateveer, 2026).

### *Condition*

#### **General definition:**

The roof condition describes the visible technical state of the roof and any deterioration caused by aging, loading, or weather influences.

#### **3.4.1 Good Condition:**

A roof without visible damage or deformations.

#### **3.4.2 Moss Formation:**

Biological growth on the roof surface resulting from moisture and aging.

#### **3.4.3 Deflection:**

A visible deformation or sagging of the roof structure.

#### **3.4.4 Roof Damage:**

Damage to the roof covering, structure, or connection details.

#### **Relevance for prefab roof analysis:**

The condition of the existing roof determines which components can remain and which must be replaced or reinforced during renovation. Structural damage or deformation may impose additional requirements on the prefab system and the underlying load-bearing structure (interviews with Rick Ebberts and Lieven Andringa, 2026).

### *Roof Installations*

#### **General definition:**

Roof installations include all technical facilities placed on or attached to the roof surface for energy generation, climate control, or infrastructure.

#### **3.5.1 No Installations:**

A roof surface without technical installations.

#### **3.5.2 Solar Panels:**

Installations for generating electricity from solar energy.

#### **3.5.3 Heat Pump:**

A technical installation for heating and cooling, with the outdoor unit placed on the roof.

#### **3.5.4 Solar Boiler:**

An installation that uses solar energy to heat water.

#### **3.5.5 Lightning Rod:**

A system that safely directs lightning strikes into the ground.

#### **3.5.6 Transmission Mast:**

A technical mast for telecommunications or data traffic.

#### **Relevance for prefab roof analysis:**

Roof installations add additional functional and structural requirements to prefab roof elements. They influence the weight, positioning of components, and required technical connections within the prefab system. In addition, installations often require specific maintenance and safety provisions that must be integrated into the roof design (Petersen, 2025; interviews with Rick Ebberts and Rogier Lateveer, 2026).

## 11.2 Morphological overview Matthijs Petersen

| Variatie in woning afwijkingen |                                 |                                                                                     |                                                                                     |                                                                                     |                                                                                     |                                                                                     |                                                                                    |                                                                                     |                                                                                     | Onderzoek: variatie in standaardisatie<br>Matthijs Petersen 1769773<br>Lectoraat: Nieuwe Energie In De Stad<br>17-12-2024 |                                                                                     |      |      |      |      |      |      |      |      |
|--------------------------------|---------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|
| Woningtype                     | Type                            |    |    |    |    |    |  |  |  |                                                                                                                           |                                                                                     |      |      |      |      |      |      |      |      |
|                                |                                 | Referentie woning - Basen                                                           | 1813                                                                                | 1813                                                                                | 1813                                                                                | 1813                                                                                | 1813                                                                               | 1813                                                                                | 1813                                                                                | 1813                                                                                                                      | 1813                                                                                | 1813 | 1813 | 1813 | 1813 | 1813 | 1813 | 1813 | 1813 |
|                                | afbouwtype                      |    |    |    |    |    |  |  |  |                                                                                                                           |                                                                                     |      |      |      |      |      |      |      |      |
|                                |                                 | 1813                                                                                | 1813                                                                                | 1813                                                                                | 1813                                                                                | 1813                                                                                | 1813                                                                               | 1813                                                                                | 1813                                                                                | 1813                                                                                                                      | 1813                                                                                | 1813 | 1813 | 1813 | 1813 | 1813 | 1813 | 1813 | 1813 |
|                                | Dak                             |    |    |    |    |    |  |  |  |                                        |  |      |      |      |      |      |      |      |      |
|                                |                                 | 1813                                                                                | 1813                                                                                | 1813                                                                                | 1813                                                                                | 1813                                                                                | 1813                                                                               | 1813                                                                                | 1813                                                                                | 1813                                                                                                                      | 1813                                                                                | 1813 | 1813 | 1813 | 1813 | 1813 | 1813 | 1813 | 1813 |
|                                | Gevel                           |    |    |    |    |    |  |  |  |                                        |  |      |      |      |      |      |      |      |      |
|                                |                                 | 1813                                                                                | 1813                                                                                | 1813                                                                                | 1813                                                                                | 1813                                                                                | 1813                                                                               | 1813                                                                                | 1813                                                                                | 1813                                                                                                                      | 1813                                                                                | 1813 | 1813 | 1813 | 1813 | 1813 | 1813 | 1813 | 1813 |
|                                | installatie aan gevel           |    |    |                                                                                     |                                                                                     |                                                                                     |                                                                                    |                                                                                     |                                                                                     |                                                                                                                           |                                                                                     |      |      |      |      |      |      |      |      |
|                                |                                 | 1813                                                                                | 1813                                                                                |                                                                                     |                                                                                     |                                                                                     |                                                                                    |                                                                                     |                                                                                     |                                                                                                                           |                                                                                     |      |      |      |      |      |      |      |      |
| Afwijkingen                    | Balkon                          |    |    |    |                                                                                     |                                                                                     |                                                                                    |                                                                                     |                                                                                     |                                                                                                                           |                                                                                     |      |      |      |      |      |      |      |      |
|                                |                                 | 1813                                                                                | 1813                                                                                | 1813                                                                                |                                                                                     |                                                                                     |                                                                                    |                                                                                     |                                                                                     |                                                                                                                           |                                                                                     |      |      |      |      |      |      |      |      |
|                                | Overstroom / toegang stroom uit |  |  |                                                                                     |                                                                                     |                                                                                     |                                                                                    |                                                                                     |                                                                                     |                                                                                                                           |                                                                                     |      |      |      |      |      |      |      |      |
|                                |                                 | 1813                                                                                | 1813                                                                                |                                                                                     |                                                                                     |                                                                                     |                                                                                    |                                                                                     |                                                                                     |                                                                                                                           |                                                                                     |      |      |      |      |      |      |      |      |
|                                | Voorbouw / toegang              |  |  |  |                                                                                     |                                                                                     |                                                                                    |                                                                                     |                                                                                     |                                                                                                                           |                                                                                     |      |      |      |      |      |      |      |      |
|                                |                                 | 1813                                                                                | 1813                                                                                | 1813                                                                                |                                                                                     |                                                                                     |                                                                                    |                                                                                     |                                                                                     |                                                                                                                           |                                                                                     |      |      |      |      |      |      |      |      |
|                                | Daklepel                        |  |  |  |  |                                                                                     |                                                                                    |                                                                                     |                                                                                     |                                                                                                                           |                                                                                     |      |      |      |      |      |      |      |      |
|                                |                                 | 1813                                                                                | 1813                                                                                | 1813                                                                                | 1813                                                                                |                                                                                     |                                                                                    |                                                                                     |                                                                                     |                                                                                                                           |                                                                                     |      |      |      |      |      |      |      |      |
|                                | installatie op dak              |  |                                                                                     |                                                                                     |                                                                                     |                                                                                     |                                                                                    |                                                                                     |                                                                                     |                                                                                                                           |                                                                                     |      |      |      |      |      |      |      |      |
|                                |                                 | 1813                                                                                |                                                                                     |                                                                                     |                                                                                     |                                                                                     |                                                                                    |                                                                                     |                                                                                     |                                                                                                                           |                                                                                     |      |      |      |      |      |      |      |      |
| Woningruimte om te bouwen      | Woningruimte om te bouwen       |  |  |                                                                                     |                                                                                     |                                                                                     |                                                                                    |                                                                                     |                                                                                     |                                                                                                                           |                                                                                     |      |      |      |      |      |      |      |      |
|                                |                                 | 1813                                                                                | 1813                                                                                |                                                                                     |                                                                                     |                                                                                     |                                                                                    |                                                                                     |                                                                                     |                                                                                                                           |                                                                                     |      |      |      |      |      |      |      |      |
|                                | Uitbouw                         |  |  |  |  |  |                                                                                    |                                                                                     |                                                                                     |                                                                                                                           |                                                                                     |      |      |      |      |      |      |      |      |
|                                |                                 | 1813                                                                                | 1813                                                                                | 1813                                                                                | 1813                                                                                | 1813                                                                                |                                                                                    |                                                                                     |                                                                                     |                                                                                                                           |                                                                                     |      |      |      |      |      |      |      |      |
|                                | Dakruimte                       |  |  |  |                                                                                     |                                                                                     |                                                                                    |                                                                                     |                                                                                     |                                                                                                                           |                                                                                     |      |      |      |      |      |      |      |      |
|                                |                                 | 1813                                                                                | 1813                                                                                | 1813                                                                                |                                                                                     |                                                                                     |                                                                                    |                                                                                     |                                                                                     |                                                                                                                           |                                                                                     |      |      |      |      |      |      |      |      |

Figure 16. Morphological overview by Petersen (2025)

| Categorien       |                      | "Standaardhuis"            |                    |                           |                          |                          |
|------------------|----------------------|----------------------------|--------------------|---------------------------|--------------------------|--------------------------|
| Woningtype       | Huistype             | Rijtheshuis (tussenwoning) | Twee onder een kap | Vrijstaand                | Rijtheshuis (Hoekwoning) | Gallerij/ portiek woning |
|                  | Daktype              | Zadeldak                   | Schilddak          | Mansardedak               |                          |                          |
|                  | Silhouette           |                            |                    |                           |                          |                          |
|                  | Dakconstructie       | Gordingkap                 | Springkap          | Nok                       |                          |                          |
| Doorvoeren/gevel | Dakkapel             | Geen dakkapel              | Op hoek/kopgevel   | Dakkapel gelijk aan gevel | Dakvorm dakkapel         | Dakkapel aan weerszijden |
|                  | Dakraam              | Geen dakraam               | Meerdere dakramen  | Plaats van dakraam        | Een dakraam              |                          |
|                  | -                    | Niks                       | Kabels             | Schoorsteen               | Ventilatie               |                          |
|                  | Installatie op dak   | Niks                       | Warmtepomp         | Zonnepanelen              |                          |                          |
| -                | Orientatie (tov zon) | Zuid                       | Noord              | Oost                      | West                     |                          |
|                  | Bezit                | Aaneengesloten             | Bespikkeld         |                           |                          |                          |
| (cijfer)         | Dakoppervlakte       |                            |                    |                           |                          |                          |
|                  | Dakhelling           |                            |                    |                           |                          |                          |
|                  | Isolatie             |                            |                    |                           |                          |                          |
|                  | Nokhoogte            |                            |                    |                           |                          |                          |

| Categorie                | A                  | B                                                                                 | C                                                                                 | D                                                                                 | E                 | F                 | G             | H | I | J | K | L | M | N | O |
|--------------------------|--------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-------------------|-------------------|---------------|---|---|---|---|---|---|---|---|
|                          |                    |                                                                                   |                                                                                   |                                                                                   |                   |                   |               |   |   |   |   |   |   |   |   |
| Dak eigenschappen        | Huistype           |  |  |  |                   |                   |               |   |   |   |   |   |   |   |   |
|                          |                    | Schilddak                                                                         | Schilddak                                                                         | Marsarddak                                                                        |                   |                   |               |   |   |   |   |   |   |   |   |
|                          | Daktype            |  |  |  | Lessenaar         |                   |               |   |   |   |   |   |   |   |   |
|                          | Silhouete          |  |  |  |                   |                   |               |   |   |   |   |   |   |   |   |
|                          | Dakconstructie*    | Grotingkap                                                                        | Springkap                                                                         | Nok                                                                               |                   |                   |               |   |   |   |   |   |   |   |   |
|                          | Bezit              | Aaneengesloten                                                                    | Bespiegeld                                                                        |                                                                                   |                   |                   |               |   |   |   |   |   |   |   |   |
|                          | Dakoppervlakte     | 50 m2                                                                             | ...                                                                               |                                                                                   |                   |                   |               |   |   |   |   |   |   |   |   |
|                          | Dakhelling         | Hellend dak                                                                       | Flauwhellend dak                                                                  | Plat dak                                                                          | Vlak dak          |                   |               |   |   |   |   |   |   |   |   |
|                          | Isolatie           | ...                                                                               | ...                                                                               |                                                                                   |                   |                   |               |   |   |   |   |   |   |   |   |
|                          | Nokhoogte          | ...                                                                               | ...                                                                               |                                                                                   |                   |                   |               |   |   |   |   |   |   |   |   |
| Doorvoeren/gevelafwijzen | Dakkapel           | Aanwezig                                                                          | Geen dakkapel                                                                     | Wel dakkapel                                                                      |                   |                   |               |   |   |   |   |   |   |   |   |
|                          | Plaats             |                                                                                   |                                                                                   | Dakkapel gelijk aan geve                                                          | Dakvorm dakkapel  | Op hoek/kop gevel |               |   |   |   |   |   |   |   |   |
|                          | Dakraam            | Aanwezig                                                                          | Geen dakraam                                                                      | Een dakraam                                                                       | Meerdere dakramen |                   |               |   |   |   |   |   |   |   |   |
|                          | Plaats             |                                                                                   |                                                                                   | Midden                                                                            | muuraansluiting   | Tegen de nok      | Tegen de goot |   |   |   |   |   |   |   |   |
|                          | Orientatie         | Achter                                                                            | Voor                                                                              |                                                                                   |                   |                   |               |   |   |   |   |   |   |   |   |
|                          | Doorvoeren         | Niks                                                                              | Kabels                                                                            | Schoorsteen                                                                       | Ventilatie        |                   |               |   |   |   |   |   |   |   |   |
|                          | Installatie op dak | Niks                                                                              | Warmte pomp                                                                       | Zonnepanelen                                                                      |                   |                   |               |   |   |   |   |   |   |   |   |
| Drainage                 | Regenbuis          |                                                                                   |                                                                                   |                                                                                   |                   |                   |               |   |   |   |   |   |   |   |   |

Figure 17. Previous versions of the morphological roof overview

### 11.3.1 Alternative clustering

#### A. Building & context

- Housing type
- Orientation
- Surroundings
  - o urban / suburban / rural
  - o shading: low / medium / high

#### B. Roof geometry

- Roof type: flat roof / pitched roof / mono-pitched roof
- Roof pitch
- Ridge height
- Roof surface area
- Roof complexity: simple / combined / multiple roof planes

#### C. Construction

- Purlin roof / rafter roof / ridge construction
- Material: timber / concrete / steel
- Load-bearing capacity: low / medium / high

#### D. Roof finish

- Roof covering
  - o bitumen / EPDM / roof tiles / green roof

- Insulation
- o none / existing / upgrade needed

#### E. Openings & penetrations

- Roof windows
- Dormers
- Penetrations:
  - o ventilation
  - o flue gas outlet
  - o cables

#### F. Roof installations

- Solar panels: position + type
- Heat pump outdoor unit
- Solar boiler
- Green roof / water retention system
- Compatibility: yes / no

#### G. Ownership / use

- Ownership: rental / owner-occupied / homeowners' association
- Accessibility: good / limited / not accessible

#### H. Preconditions

- Regulations: aesthetic requirements / permit required
- Safety: fall protection required
- Maintenance access