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Planting the Seed for Renovation

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Barriers and drivers influencing the use of bio-based insulation materials in renovation of existing housing stock in the Netherlands

Recommendations on how to increase the manufacturing of Bio-based Insulation Materials in the Architecture, Engineering and Construction industry

Master Thesis
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Abstract

The European Climate Pact made in 2021 states that by 2030 Europe should record a CO_2 reduction of 55% compared to 1990, and be completely climate-neutral by 2050. In 2022 the built environment was responsible for 12% of all greenhouse gas emissions in the Netherlands, mainly due to burning fossil fuels for space heating. In order to reach climate neutrality in housing stock, efforts need to be made to reduce the need for fossil fuels. Recently, the Dutch government is taking steps towards renovating existing housing stock by ways of investing in Bio-based Building Materials (BBBM). Besides the need to renovate existing housing stock, interest in circular economy has been increasing for years in the building sector. In order to solve the climate goals set by the European Climate Pact and the Klimaatakkoord, Bio-based Insulation Materials (BBIM) can be used to increase insulation and thereby decrease fossil fuel use in existing housing stock. As of this moment, a lot is known about barriers and drivers for using BBBM, however, little is known about how to overcome these barriers, or how to apply these drivers. This research aims to increase knowledge on the subject of bio-based insulation materials and how to stimulate their use in future renovation projects. To achieve this, interviews are held with manufacturers, as this research determines them to have the biggest impact. The goal of this research is to analyse the barriers and drivers gained from the literature and interviews, in order to create recommendations for policy makers to increase the use of BBIM in renovation of existing housing stock. The findings suggest that manufacturing of BBIM needs to increase in the Netherlands. Scaling BBIM in Dutch renovations requires addressing the knowledge gap as a priority, supported by policies that enhance financial incentives, streamline certifications, and promote visible demonstration projects. Smaller manufacturers would benefit from targeted subsidies, training programs, and transparent certification pathways, while larger companies could be incentivized to integrate BBIM into their portfolios through public tenders focused on sustainability.

Key words: Bio-based Insulation Materials, AEC industry, Manufacturers, Housing Renovation, Innovation Theory, Dutch Context

Preface

Dear reader,

Welcome to my thesis, which was written for the completion of the Management in the Built Environment master track at the TU Delft. This track is part of the larger Architecture, Urbanism and Building Sciences master, following the Bachelor's degree of the same name, known in Dutch as Bouwkunde. I have completed my Bachelor in 2021, and have taken two years to write this thesis.

The road to completing my master with this thesis was a difficult one. I have struggled immensely with having to work on my own, instead of in groups, as we have done for a large part of the master courses. I have learned to check in with my superiors to compare the expectations I set for myself with theirs, which usually meant that I was aiming too high. This, combined with my perfectionism, often hindered me in starting at all, causing me to fall behind on my deadlines and to have difficulty conveying my thoughts to others. Eventually, paired with a late ADHD diagnosis, I figured out how to set up structure for myself, and I discovered how truly supportive my supervisors, friends and family are.

My supervisors, Henk and Erwin, made themselves available to me every two weeks, so I could gain some semblance of structure, which forced me to make progress at least a little before every meeting. For this I am infinitely grateful, since this started the ball rolling again and allowed me to gain momentum and to keep my motivation up. Almost every meeting gave me new-found enthusiasm to tackle the next subject, one problem at a time. I would also like to thank Floor, from The Green Village, who helped me connect with themes as well as people, within my topic. On top of this, somewhat towards the end of my thesis, I found great support in my friends and family, who literally opened their doors for me to give me a place of structure for the rest of the time. Special mentions to Hidde, Anna, Janneke, Martin, Lotte, Carlijn, Lynn, Rebekka and Nina, who made this a much more bearable exercise.

With that, I hope you enjoy reading this thesis, and I hope you learn a little about bio-based insulation materials!

Valerie Erd
23/06/2025

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List of Abbreviations

Abbreviation	Definition	Pg.
AEC Industry	Architecture, Engineering and Construction Industry	8
BBBM	Bio-based Building Material(s)	8
BBIM	Bio-based Insulation Material(s)	9
BBM	Bio-based Material(s)	8
CIM	Conventional Insulation Materials [fossil-based and mineral]	16
CLT	Cross-Laminated Timber	19
DMP	Data Management Plan	16
EPD	Environmental Product Declarations	28
FAIR Data	Findable, Accessible, Interoperable and Reusable Data	17
FBIM	Fossil-based Insulation Material(s) [e.g. EPS/PUR/PIR/XPS]	21
LCA	Life Cycle Assessment	27
MRQ	Main Research Question	10
MPG	MilieuPrestatie Gebouwen	43
NABB	Nationale Aanpak Biobased Bouwen	9
NMD	Nationale Milieudatabase	20
SQ	Sub-Question	10
TCO	Total Cost of Ownership	26

List of Translations

English	Dutch
Cavity Wall	Spouwmuur
Garden Flat	Benedenwoning
Houses with Balcony Access	Galerijflat
Intermediate floor	Verdiepingsvloer
Phase Shift	Faseverschuiving
Stakeholders	Belanghebbenden
Tenement house	Portiekflat
Terraced House	Rijtjeshuis
Upstairs Apartment	Bovenwoning

1. Introduction

The urgency to mitigate climate change has led to significant policy developments across Europe, aiming for substantial reductions in greenhouse gas emissions. The built environment, being a major contributor to these emissions, is under scrutiny to adopt more sustainable practices. This chapter outlines the problem statement, delves into the potential of bio-based building materials (BBBM), identifies the research gap, and presents the research questions guiding this study.

1.1 Problem Statement

The European Climate Pact made in 2021 states that by 2030 Europe should record a CO_2 reduction of 55% compared to 1990, and be completely climate-neutral by 2050 (European Union, n.d.; Ministerie van Volkshuisvesting en Ruimtelijke Ordening [VRO], 2022, p. 10). Climate neutrality is achieved by having net-zero CO_2 emissions, which means reducing the production of greenhouse gasses and compensating remaining emissions through climate action (The Climate Neutral Certified Standard, 2022; United Nations Framework Convention on Climate Change [UNFCCC], 2021). In alignment with the Paris Agreement in 2015, the “Klimaatakkoord” (climate agreement) was signed in the Netherlands in 2019 (Ministerie van Economische Zaken en Klimaat [EZK], 2020). The Klimaatakkoord is an agreement between many organisations and firms in the Netherlands to combat greenhouse gas emissions across six sectors: industry, electricity, mobility, agriculture, built environment, and land use (Ministerie van EZK, 2020; CBS, n.d.).

In 2022 the built environment was responsible for 12% of all greenhouse gas emissions in the Netherlands, mainly due to burning fossil fuels for space heating (CBS, n.d.). According to the IPCC it is becoming increasingly difficult to limit global warming to 1,5°C, therefore it is necessary to speed up the energy transition in the built environment (The Intergovernmental Panel on Climate Change [IPCC], 2022; Ministerie van VRO, 2022, p. 5). In order to do this, efforts need to be made to reduce the need for fossil fuels, which is why the Dutch government aims to completely phase out fossil fuels for heating and cooling of buildings by 2040 (Ministerie van VRO, 2022, p. 10). This can be achieved by decreasing energy use, optimising existing facilities, improving heat insulation, providing renewable energy generation and using or switching to fossil-gas-free and efficient appliances (Ministerie van VRO, 2022, p. 21).

The Dutch government is taking steps towards renovating existing housing stock through the Nationaal Isolatieprogramma (national insulation programme) (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties [BZK], n.d.). The focus of the Nationaal Isolatieprogramma is to renovate 2,5 million residences before 2030, by providing renovation subsidies to municipalities, landlords, and homeowners (Ministerie van BZK, n.d.). Since 2021, the housing stock of dwellings with low energy labels has decreased by 11,2% (Ministerie van VRO, 2025a), leaving approximately 1,3 million dwellings that need to be renovated before 2030 (Ministerie van VRO, 2022, p. 13). For these renovations, the Dutch government has recently started investing in BBBM by creating the *Nationale Aanpak Biobased Bouwen* (national approach to bio-based construction) (De Jonge, Heijnen, Adema, Jetten & Adriaansens, 2023). The main aim of their approach is to contribute to national targets on carbon reduction, nitrogen reduction, circular economy, nature and biodiversity and spatial quality. One of these targets is to execute at least 30% of renovation efforts by 2030 using bio-based materials (De Jonge, Heijnen, Adema, Jetten & Adriaansens, 2023).

1.2 Bio-based Building Materials

Besides the need to renovate existing housing stock, interest in circular economy has been increasing for years in the building sector (De Graaf, Schuitemaker, Hamada & Gruis 2022). Circularity in the architecture, engineering and construction (AEC) industry encompasses the preservation of natural resources by tracking, quantifying and optimizing the use of building materials (De Graaf et al., 2022). Part of this can be a shift to using sustainable materials, such as bio-based materials (BBM). They are unlimited and renewable, and they can have a substantial impact on reducing carbon emissions in the construction industry (Milind & Arti, 2024).

BBBM are building materials made from animal material or from fungi, plants, bacteria that are ecologically grown, harvested, used and reused (Ministerie van BZK, 2023). This also means that they can be composted at the end of their lifespan, returning to nature (Koster, Schrotenboer, Van der Burgh, Dams, Jacobs, Versele & Verdoodt, 2020). BBBM have gained appreciation due to various qualities. Growing vegetative BBBM absorbs CO_2, meaning it forms a natural storage of greenhouse gasses, which continues once integrated in a finished building project (Fraanje & Nijman, 2021; Van Dam & Van den Oever, 2019).

Due to its absorption of CO_2, processing wood, for example, into building materials results in a negative CO_2 emission during its entire lifespan (VVan Dam & Van den Oever, 2019). Additionally, BBBM are an inexhaustible source of building materials, as they can be grown and regrown indefinitely. This could solve (part of) the material shortage that has not recovered since the corona crisis (Ministerie van Algemene Zaken, 2023). However, according to the Dutch Ministry of the Interior and Kingdom Relations, BBBM must be able to grow back within 100 years after harvesting, and it has to leave the harvest site in an ecologically sound condition (Ministerie van BZK, 2023). At the moment, BBBM are most extensively used as thermal or acoustic insulation. As previously mentioned, phasing out fossil fuels for heating and cooling of buildings can be achieved by (among other things) decreasing energy use and improving heat insulation. By using bio-based insulation materials (BBIM) fossil fuels can be phased out, as well as adding to circularity goals.

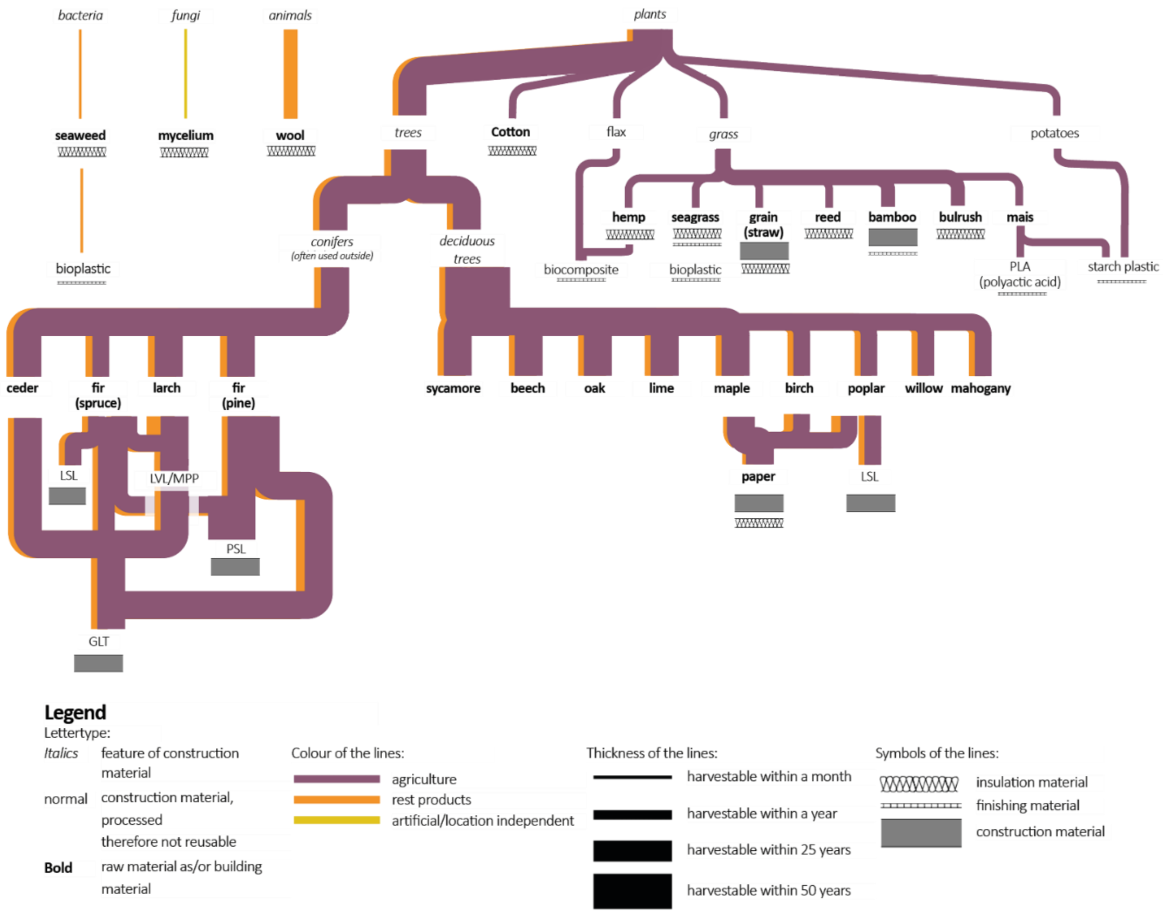

Figure 1 – Scheme Growth BBBM (translated from Ministerie van BZK, 2023)

Conversely, BBBM take time to grow ranging from one month to 50 years (Ministerie van BZK, 2023, Figure 1). It also takes up space to grow in large quantities. Where there is not enough space to grow BBBM, they need to be imported from abroad, which then again increases the emissions of greenhouse gasses. Additionally, it may be necessary to combine BBBM with composite materials or additives in order to achieve lawfully required properties such as fire resistance, water (ab)sorption, hygro-thermal stability (Heil, Perricone, Gruber & Guéna, 2023). The AEC industry is also hesitant to change its way of working, which further discourages use of BBBM, as they are relatively new to the industry. This resistance to change, known as the 'mirroring trap' (Colfer & Baldwin, 2016; Hall, 2018), reinforces established industry practices and slows the adoption of innovations such as BBBM. Consequently, BBIM face three major hurdles: cost, quality assurance, and a lack of knowledge on implementation (F. Hoogenboezem, personal communication, April 10, 2024).

In the Netherlands, several regional initiatives promote bio-based construction. The Nationale Aanpak Biobased Bouwen (NABB) has a 30-30-30 ambition: in 2030 at least 30% of newly built housing as well as renovation of existing housing has to contain at least 30% BBBM (De circulaire bouweconomie, 2025). Circulair Friesland, a network of over 150 companies, knowledge institutions, and governments, plays a crucial role in driving the transition to a circular economy in Friesland. Their focus includes sustainable construction, bio-based materials, and the implementation of circular business models in the built environment (Vereniging Circulair Friesland, 2025). Another initiative, ECOhûs Fryslân, is dedicated to showcasing and developing sustainable and circular building techniques. By collaborating with businesses, knowledge centres, and policymakers, ECOhûs Fryslân aims to accelerate the adoption of BBBM and other circular solutions in residential and commercial construction (Bouwend Nederland, n.d.; ECOhûs Fryslân, n.d.-a, n.d.-b).

1.3 Research Gap

To address the climate goals set by the European Climate Pact (European Union, n.d.) and the Klimaatakkoord (Ministerie van EZK, 2020), BBIM can be used to increase insulation and reduce fossil fuel consumption in existing housing stock. Even though the Dutch government has given signals of wanting to increase the use of BBIM (De Jonge et al., 2023), this has not yet happened sufficiently. Preliminary results on the use of BBBM in new housing projects show that in 2024 less than 3% of the total mass is bio-based (Ministerie van VRO, 2025b). Data about renovation was not collected in 2024, but will be collected for 2025. It can be assumed that BBIM in housing renovation has a similarly low percentage. While there is substantial knowledge about the barriers and drivers for using BBBM (Jones & Brischke, 2017; Koster et al., 2020; Ministerie van BZK, 2023; Rebergen, 2022; TKI Bouw en Techniek, 2024), there is a significant gap in understanding how to overcome these barriers and effectively apply these drivers.

This research aims to expand knowledge on how to increase the implementation of BBIM in Dutch renovation housing projects. The focus will be exclusively on plant-based BBM due to their CO_2 reductive qualities during growth, as opposed to animal-based BBM. For this research, interviews will be conducted with manufacturers of insulation materials, identified as currently having the most significant impact on the adoption of BBIM. For a sustainable future, it may be necessary for all stakeholders in the AEC industry to adopt and promote greener technologies. However, the primary focus remains on manufacturers, the reason for which will be explained later in the thesis.

1.4 Research Questions

This leads to my main research question (MRQ): **"How can the use of bio-based insulation materials be stimulated in renovation of existing housing stock in the Netherlands?"**

In order to answer this question, the following sub-questions (SQ) have been formulated:

1. Which bio-based building materials are (or have the potential to be) used as insulation in housing renovation projects?
2. How can previously identified barriers be overcome, and drivers be used, to increase the production of bio-based insulation materials for renovation of existing housing stock?
3. What innovation-driven approaches can help scale up the manufacturing of bio-based insulation materials for housing renovation in the Netherlands?

Firstly it is necessary to know which bio-based materials are in play, and which have the most potential for renovation in the Dutch housing sector. Secondly, there are three main barriers identified in literature for incorporating the use of bio-based materials, but it is unclear how these can be overcome or how drivers can be used effectively. Lastly, the known barriers can be combined with innovation theories, in order to find out what approaches can be used to stimulate production of bio-based insulation materials. This forms a basis for answering the main research question, to provide strategic recommendations for policymakers on how to stimulate the use of bio-based insulation materials in the renovation of existing housing stock in the Netherlands.

2 Research Methods

To answer the research questions in section 1.4, the designed research methodology is explained in this part. Firstly, the type of study, its methods and outputs are described. Secondly, the data collection is outlined, after which the data analysis and the data plan is explained. Lastly, the ethical considerations for this research are presented.

2.1 Research Design and Output

In order to answer the research questions provided in section 1.4, an exploratory qualitative approach is chosen. This approach is chosen to gain a deeper understanding of the barriers and drivers influencing the production of BBIM in the Netherlands. This study aims to translate these insights into actionable strategies for policy makers. The research takes part in three phases (theoretical study, empirical research and synthesis & conclusion), with the SQs overlapping two or more phases (see Figure 2).

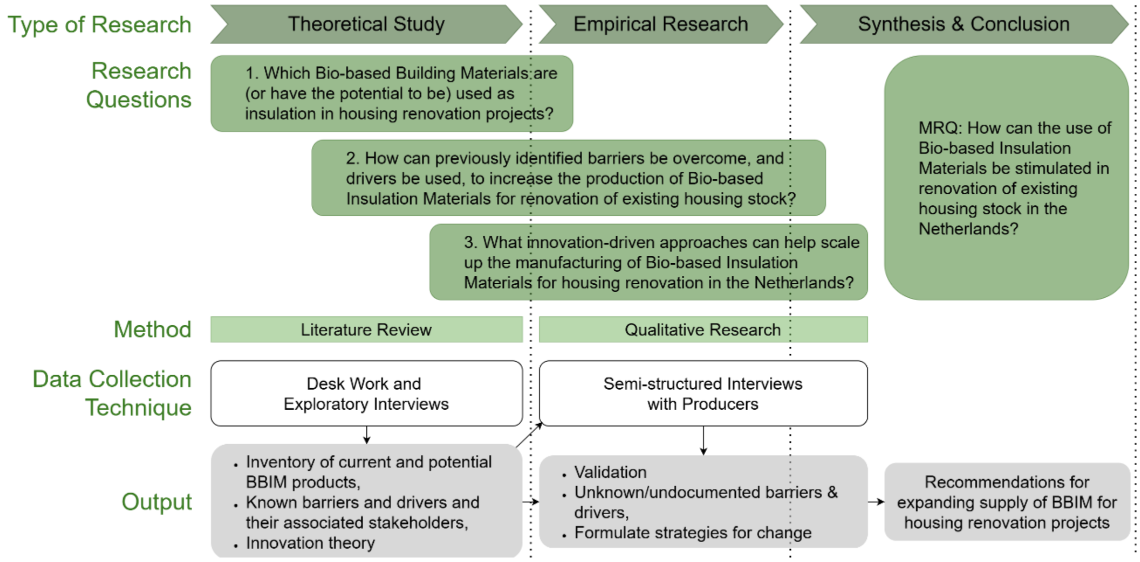

Figure 2 – Research Design Framework (own work)

To answer the first SQ "Which bio-based building materials are (or have the potential to be) used as insulation in housing renovation projects?", primarily a literature review was conducted, supplemented by exploratory and semi-structured interviews as part of the empirical research. The literature review was conducted by using search engines such as Google Scholar and Scopus, using key words like "biobased insulation materials", "AEC industry", "thermal insulation", "Dutch housing renovation' and the individual chosen BBIM materials. The search was done in English, German and Dutch, and a selection was made based on recency, citations and source. A large part of the literature review stems from government (programme) publications, as well as publications from early adopters. This provides a comprehensive overview of existing and future BBIM, their properties, applications, and potential for use in renovation projects. This method is appropriate because it allows for a structured analysis of previous research, policy documents, and technical reports, ensuring a broad and well-founded understanding of available materials. However, given the evolving nature of bio-based insulation technologies and market developments, exploratory and semi-structured interviews with industry experts (manufacturers) complement the literature review. By conducting exploratory interviews with BBIM manufacturers before formulating questions for semi-structured interviews, the empirical research can be more targeted. The combination of these methods provides insights into emerging materials, practical challenges, and industry perspectives that may not yet be well-documented in academic literature. The goal of answering this sub-question is to establish a clear and up-to-date inventory of bio-based insulation materials, which then informs the second sub-question regarding barriers and drivers for increasing production. This, in turn, directly supports the main research question by identifying key materials that need to be considered when scaling up production for housing renovation projects.

SQ2 "How can previously identified barriers be overcome, and drivers be used, to increase the production of bio-based insulation materials for renovation of existing housing stock?" is addressed through a combination of theoretical study and qualitative empirical research. The theoretical study provides a solid starting point by outlining known barriers and drivers from existing literature, which helps identify existing challenges and opportunities. However, the barriers and drivers explored are specifically informed by the focus on insulation manufacturers (both bio-based as well as fossil-based) as key stakeholders. By prioritizing the perspectives of manufacturers, the scope of analysis can be narrowed down to those factors that most directly impact their production processes. Subsequently, qualitative research, particularly semi-structured interviews, is the most suitable method for this question because it allows for in-depth exploration of the experiences and perspectives of BBIM manufacturers. This method enables the discovery of unknown or undocumented barriers and drivers, offering a deeper understanding of the practical challenges and opportunities within the industry. The semi-structured format also allows flexibility to explore new ideas that may emerge during the interviews. This approach is appropriate because it provides both theoretical and practical insights, ensuring that the strategies proposed are grounded in reality. This SQ builds directly on the findings of SQ1 by addressing the barriers to increasing the production of BBIM identified in the inventory, and the drivers that could help scale up their production. The solutions proposed here provide the necessary groundwork for answering the final SQ, which considers the role of policymakers in implementing these strategies. This ultimately feeds into the main research question, providing actionable insights for overcoming obstacles and leveraging opportunities to increase the production of bio-based insulation materials for housing renovation projects.

To address SQ3 “What innovation-driven approaches can help scale up the manufacturing of bio-based insulation materials for housing renovation in the Netherlands?”, both theoretical study and empirical research are explored, followed by insights gathered in the synthesis & conclusion phase. The theoretical background is important because it helps understand the role of policies and regulations in supporting the use of sustainable materials, providing a foundation for the policy landscape. Semi-structured interviews with BBIM manufacturers are well-suited for this question because they allow for an in-depth examination of how policies have impacted production in the past, and how they might be leveraged in the future. This method is appropriate because it enables the gathering of nuanced perspectives on the effectiveness of current policy frameworks and potential areas for improvement, which is critical for understanding how policy makers can drive change in production practices. SQ3 expands on SQ2 by identifying policy interventions that can help overcome barriers and leverage drivers in the production of BBIM. The findings from both the literature and empirical research offer concrete policy mechanisms for scaling up production. The insights from this SQ contribute directly to the MRQ by providing the policy-oriented solutions that enable a broader framework to increase the production of bio-based insulation materials for housing renovation projects.

Lastly, the MRQ “How can the use of bio-based insulation materials be stimulated in renovation of existing housing stock in the Netherlands?” is answered in the synthesis & conclusion phase, drawing on the findings from the theoretical study and empirical research. The literature review provides the foundational knowledge of bio-based insulation materials, while semi-structured interviews with manufacturers validate and refine these insights. Such a combination of methods is ideal for synthesizing both theoretical understanding and real-world perspectives into actionable recommendations. This synthesis is essential for answering the main research question, as it integrates the materials identified in SQ1, the strategies for overcoming barriers and leveraging drivers from SQ2, and the policy recommendations from SQ3 into a cohesive framework for scaling up production. By bringing together technological, production, and policy-related insights, this research provides a well-rounded, evidence-based solution for increasing the availability of bio-based insulation in housing renovations.

The ultimate goal of this research is to provide strategic recommendations for policy makers to expand the production (and with that the supply) of bio-based insulation materials in the Netherlands for housing renovation projects.

2.2 Data Collection

This research focuses on understanding the barriers and drivers behind producing BBIM in housing renovation projects. This includes, as previously described, literature reviews and semi-structured interviews, in order to expand written knowledge on this subject. This sections elaborates on the information which was collected in the proposed research methods; literature review, exploratory interviews and semi-structured interviews.

2.2.1 Literature Review

Literature reviews are useful to assess the current state of relevant knowledge and to form a basis for explanatory ideas or theories. In the literature study of this research, data was collected regarding BBIM, barriers and drivers and systemic innovation.

Theoretical background on BBIM was divided into an overview of first BBBM, then BBIM and lastly BBIM in renovation. Using this structure allowed for a more general context of BBBM, which then narrowed down towards which BBIM can, or have the potential to, be used in housing renovation projects. For this background, data was collected about the history of BBBM, technical specifications of BBIM and their application in housing renovation. The necessary information was collected from various sources, including (but not limited to) academic papers, government publications and product pamphlets.

From the identified BBIM, corresponding barriers and drivers could be found. At this point, a stakeholder focus was made, after this the literature elaborated on three main barriers found (cost, quality assurance and knowledge) as well as (possible) drivers for the production of BBIM. For the stakeholder focus, government reports were studied to derive which stakeholder(s) need to be encouraged in order to promote the production of BBIM. This stakeholder focus remained prevalent in determining barriers and drivers. The barrier regarding cost considers financial investment into starting a new production (line), the risk and profitability, but also the final selling price compared to similar products. Quality assurance covers consistency in product performance and meeting legal requirements, and knowledge is explored as a barrier in terms of material properties, expertise on how to manufacture BBIM, how to apply them in building projects and awareness about the availability of BBIM. Lastly, the Dutch government has made efforts in recent years to promote the use of BBIM in the AEC industry by means of subsidies, certifications and laws and regulations. These barriers and drivers were explored through literature containing academic papers, policy documents, government publications and product pamphlets.

Lastly, the literature review investigated systemic innovation in the AEC industry. Literature on diffusion of innovations, the mirroring trap and strategic niche management was explored in order to translate this into actionable steps to be taken to increase the production of BBIM. Literature on systemic innovation was collected through academic papers and textbooks.

2.2.2 Exploratory interviews

Additionally, exploratory interviews were conducted with BBIM manufacturers in the Netherlands, Belgium, Germany, and Austria. Surrounding countries were added to this research as they have somewhat similar climates, as well as similar social structures. For the selection of interviewees, the main focus lied with BBIM manufacturers. The companies were found by using a combination of personal contacts and targeted online searches. Initially, professionals who are involved in the bio-based insulation industry were approached. To ensure a broader and more representative sample, additional interviewees were identified through distribution websites supplying bio-based insulation materials. This approach allowed for the inclusion of manufacturers working with various BBIM to explore relevant experience in the production of bio-based insulation. These interviews provide insights into market dynamics, production challenges, and regulatory barriers. Key topics included material availability, certification requirements, cost factors, market demand, and the role of governments in scaling production. Additionally, factors influencing international expansion, such as language barriers in database inclusion, were explored.

Alongside manufacturers, interviews were also conducted with professionals from the renovation sector, offering a broader understanding of the practical challenges and decision-making processes when adopting BBIM in renovation projects. This includes insights into installation preferences, cost considerations, and regulatory hurdles. These findings complemented the perspectives from manufacturers and contributed to a more comprehensive understanding of the industry landscape.

The findings from both manufacturers and renovation professionals contributed to identifying key stakeholders as well as documented and undocumented barriers and drivers, complementing the literature review and informing the subsequent semi-structured interviews.

2.2.3 Semi-structured Interviews

To gain a deeper understanding of the factors influencing the production of BBIM, semi-structured interviews were conducted with insulation manufacturers in the Netherlands and Belgium. These interviews built upon insights gathered from the previous exploratory interviews and the literature review. The interview questions were designed to capture the motivations and challenges of BBIM manufacturers and to identify key barriers and drivers that influence production decisions.

The interviewees were selected partly through snowball sampling, as well as purposive sampling in the same way as the exploratory interviews, focusing on manufacturers who produce plant-based insulation materials, fossil-based insulation materials, or both. Ideally, 8-10 interviews are conducted to maintain a manageable dataset while still capturing diverse insights. However, after 5 exploratory interviews, only 6 participants could be found for semi-structured interviews. The questions were structured to align with Rogers' (2003) innovation-decision process, exploring the stages of knowledge, persuasion, decision, implementation, and confirmation. The interviews were conducted either in Dutch or English, depending on the language the interviewee is most comfortable with.

The interview questions were divided into six parts, each addressing different aspects of the manufacturers' experiences and decision-making processes:

1. **Introduction**:
   This section gathered background information about the interviewee, their role, the company's main product, and the driving force behind the establishment of the company. The questions aimed to explore why certain materials were chosen for production and whether the company is currently considering or experimenting with (other) bio-based materials, including those used in renovation projects.
2. **Cost**:
   These questions explored how manufacturers handle the initial investment costs, the challenges they face, and the benefits of producing bio-based materials (if they do). For those not currently producing BBIM, the focus was on what would need to change for them to consider it. The goal was to understand the economic factors involved in deciding whether to enter the bio-based market.
3. **Quality Assurance**:
   Questions in this section addressed how manufacturers ensure product consistency while maintaining material integrity. The questions focussed on potential challenges that bio-based materials might present in terms of legal requirements and product quality. They also explored whether manufacturers see potential adjustments to make BBIM quality assurance more achievable.
4. **Knowledge**:
   This part explored how the properties of materials, such as fire resistance and insulation value, create both opportunities and obstacles for manufacturers. For companies not yet producing BBIM, questions addressed the perceived challenges or benefits of incorporating bio-based materials. It also examined how manufacturers acquire the expertise to produce and apply new materials, as well as their efforts to increase familiarity and acceptance of these materials among other stakeholders in the built environment.
5. **Drivers**:
   Here, interviewees were asked to evaluate the role of policy instruments such as certifications, laws, regulations, and subsidies in driving the production of bio-based materials, both for those currently producing BBIM and those who do not (yet). They were also asked about government communication regarding climate goals and how cooperation with other stakeholders (such as architects and contractors) influences their innovation efforts.
6. **Closing**:
   The final part invited interviewees to reflect on any additional barriers or drivers they believe are crucial to the production or potential production of bio-based materials. They were asked to provide their perspective on the main barriers and drivers for scaling up production and to suggest measures that could help overcome obstacles for manufacturers, whether currently producing BBIM or not.

In conclusion, the findings from these semi-structured interviews offered a detailed understanding of the practical realities faced by manufacturers in the bio-based insulation industry. This data provided valuable insights into the current state of production and help inform policymakers on how to support the scaling of bio-based insulation materials in the Netherlands.

2.3 Data Analysis

Data from the literature review and qualitative research was processed in the way shown in Figure 3.

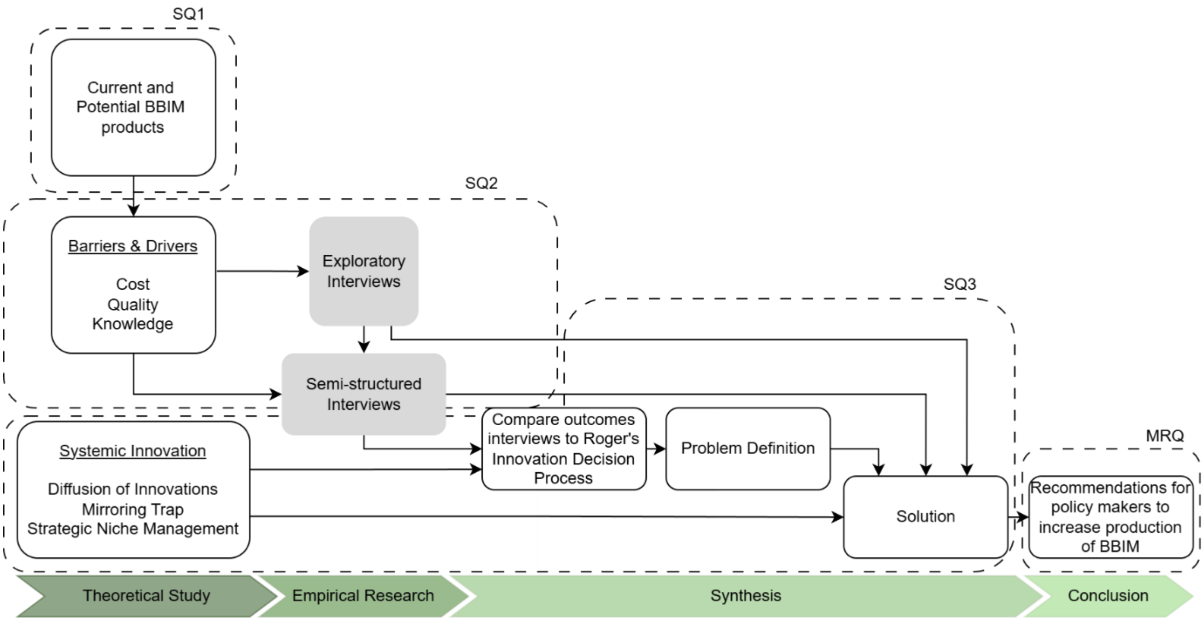

Figure 3 – Data Analysis Process (own work)

Literature on current and potential BBIM products laid the foundation for sub-question 1 as well as for literature on barriers and drivers. These formed a basis for exploratory interviews, which together created the background for the semi-structured interviews, largely answering sub-question 2. Outcomes from these interviews were compared to Rogers' Innovation Decision Process (2003) to define where the problem lies for the upscaling of BBIM production in the Netherlands. By combining information gained from semi-structured interviews, as well as literature on systemic innovation, possible solutions could be specified (sub-question 3). These solutions were used as input for formulating recommendations for policy makers to increase the production of BBIM in the Netherlands for renovation of existing housing stock, which answers the main research question of this thesis.

The interview data was analysed using ATLAS.ti, a software that enables structured coding of interview transcripts, making it easier to organise and identify emerging patterns. The coding structure was initially derived from the literature and consisted of four main categories: cost, quality assurance, knowledge, and drivers. However, during the analysis process, it became evident that "drivers" was not an independent category but rather a subdimension within each main category. Furthermore, "policy" emerged as a distinct category, addressing government incentives and regulatory frameworks. The final coding structure thus consisted of four main categories: Cost, Quality Assurance, Knowledge, and Policy, each containing both barriers and drivers.

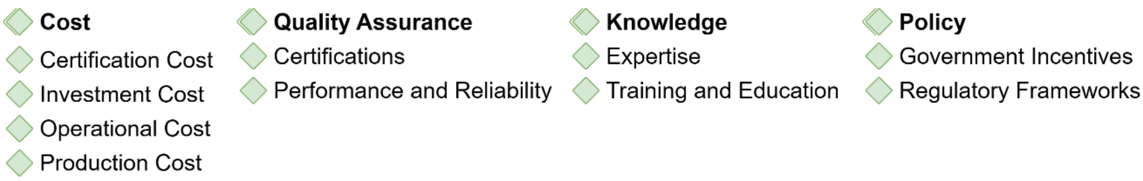

Figure 4 – ATLAS.ti codes used for analysing interviews (own work)

To ensure clarity and manageability during the initial stages of coding, a limited set of general codes was applied, namely the main categories. This approach allowed for easier navigation of the transcripts and provided the flexibility to create sub-codes based on emerging findings. Sub-codes were introduced to capture specific barriers and drivers within each main category. Each quotation in ATLAS.ti was assigned at least one sub-code, as well as a classification as either a *barrier*, a *driver*, or, in some cases, both. Figure 4 illustrates the coding framework, which is structured as follows:

The category **Cost** encompasses four subcategories that reflect the financial implications of BBIM production and adoption:

- Certification Costs: This includes the financial burden associated with acquiring third-party certifications necessary for market access. Smaller companies, in particular, face difficulties in absorbing these costs, while larger companies can often leverage these certifications as drivers of credibility and market expansion. In addition, regulatory compliance often requires repeat testing and documentation, adding further to these costs over time.
- Investment Costs: This subcategory refers to the initial capital expenditures required to set up production facilities, invest in technology, and scale up operations. These costs include infrastructure development, advanced machinery, and technology upgrades. Furthermore, long-term contracts with suppliers and distribution partners represent a significant investment that can drive cost efficiency but also create barriers for smaller companies that lack the capital to engage in such long-term commitments. Time is a critical factor in this category, as delays in scaling up or acquiring machinery translate directly into higher costs.
- Operational Costs: These are the ongoing expenses associated with running a production facility. This includes energy consumption, wages, maintenance of equipment, logistics, and general administrative costs. For BBIM manufacturers, these costs are influenced by factors such as the energy-intensive nature of production, the need for specialized labour, and the maintenance of sustainable supply chains. Unlike Production Costs, which focus more on the input materials and their conversion into products, Operational Costs are related to the day-to-day activities required to keep the business running efficiently.
- Production Costs: This category captures the expenses related to the transformation of raw materials into finished products. These costs include the procurement of raw materials, along with energy costs tied directly to the manufacturing process. Labour expenses are also considered part of Production Costs, particularly when specialised skills are required to handle biobased materials. For smaller companies, certification requirements can add a layer of complexity to production, increasing costs due to regulatory compliance. Moreover, the final price of the product is heavily influenced by these production-related expenses, which directly impacts market competitiveness.

The category **Quality Assurance** reflects the need for consistent compliance with industry standards and expectations:

- Certifications: This subcategory refers to the need for compliance with formal standards, including third-party verifications and industry certifications. While these certifications are crucial for market access, the path to certification is often costly and time-consuming, particularly for smaller companies. In addition to the costs of testing and documentation, international certifications pose additional barriers. For instance, products that are certified in one country often require re-certification to be sold across borders, due to differing regulatory frameworks and testing standards.
- Performance and Reliability: This includes the comparative analysis of BBIM against conventional insulation materials (CIM) in terms of thermal performance, durability, and safety standards. Interviewees frequently cited concerns about fire safety and insulation performance as critical considerations for scaling up BBIM.
  The Performance and Reliability subcategory captures the comparative effectiveness of BBIM versus CIM. This includes metrics such as thermal conductivity, fire resistance, and long-term durability. Additionally, achieving consistent quality across batches can be difficult for smaller manufacturers who lack advanced production facilities.

The **Knowledge** category reflects both the technical understanding and the broader industry awareness necessary for the successful adoption of BBIM. This category is subdivided as follows:

- Expertise: This includes not only the technical capabilities required to produce and install BBIM but also market knowledge, awareness of sustainable practices, and familiarity with evolving regulations. Additionally, awareness of market demand and the intrinsic drive towards climate goals are captured here.
- Training and Education: This includes capacity-building initiatives such as industry workshops, training programs, and knowledge transfer. Expanding practical knowledge through education is

crucial for mainstreaming BBIM, particularly among installers and contractors unfamiliar with these materials. Importantly, this subcategory also includes networking and collaboration as key aspects of Strategic Niche Management (SNM). Collaborative networks, where manufacturers share expertise and market insights, are vital for accelerating the learning curve and building trust in biobased products.

The **Policy** category emerged as a critical driver and barrier during the analysis. Unlike the initial framework, where it was not separately distinguished, it became evident that policy mechanisms deeply influence the feasibility of BBIM adoption. The subcategories are as follows:

- Government Incentives: This subcategory covers subsidies, tax breaks, and financial incentives aimed at encouraging sustainable building practices. These incentives can mitigate the high initial costs and reduce financial risks for manufacturers, driving innovation.
- Regulatory Frameworks: This includes the broader policies and regulations that govern the production and application of BBIM and CIM. Strict regulatory requirements for certification and product registration, both at the national and European levels, are important barriers. Lobbying and international regulatory alignment are also key factors influencing market access.

The analysis begins with an inductive thematic approach to identify recurring patterns and insights emerging from the interview data. This allows for a grounded understanding of the challenges and opportunities perceived by industry stakeholders. Subsequently, the findings are examined through the lens of established innovation theories, including the mirroring trap, diffusion of innovation, and strategic niche management. This theory-informed phase of the analysis helps to structure the interpretation and connect the empirical findings to broader conceptual frameworks.

2.4 Data Plan

For this thesis, a data management plan (DMP) was made and checked by the TU Delft data steward to ensure the safe processing of collected data. It follows TU Delft guidelines (TU Delft Library, n.d.) and it outlines the approach to managing research data throughout the project's lifecycle. The DMP ensures that all data is handled in accordance with ethical standards and the FAIR principles: Findable, Accessible, Interoperable, and Reusable (Wilkinson et al., 2016):

1. **F**indability: to make this report findable for humans and computers, it is uploaded to the TU Delft repository, accompanied by keywords representing the research done in this thesis.
2. **A**ccessibility: the report is openly accessible through the TU Delft repository.
3. **I**nteroperability: the anonymized interview data is not shared, so the data is processed and structured in a standardized format that ensures clarity and ease of understanding for future analyses, if needed. The methods and analytical approach are well-documented in the thesis, allowing other researchers to apply similar techniques or use the derived findings in related studies.
4. **R**eusability: the data collected during the project is used solely within the MSc thesis, and is not shared externally in raw form. However, the derived conclusions and analyses, including findings related to barriers and drivers for using BBIM, will be made publicly available in the thesis via the TU Delft repository. This allows for the reuse of the research outcomes, while respecting privacy and confidentiality constraints.

The research involved qualitative data collection through interviews with manufacturers in the BBIM industry. For the collection of this data a consent form was signed, which can be found in Appendix A. The data types include:

- *Personal Identifiable Information (PII)*: Information like names, emails, and company details are collected for administrative purposes, such as obtaining informed consent and communication with interview participants.
- *Audio Recordings*: Interviews are conducted online via Microsoft Teams and recorded in MP3 format.
- *Transcriptions*: The audio recordings are transcribed manually into .docx and .pdf formats.
- *Data on Barriers and Drivers*: This includes coded data from interview transcriptions, analysed using ATLAS.ti software, and stored in .xlsx format.

Ethical considerations are a key component of the DMP. The research involves human subjects, and informed consent was obtained from all interviewees. Personal data, such as contact information and professional opinions, was processed in compliance with privacy regulations. Data was anonymized for analysis, and raw data, such as interview recordings and consent forms, is not shared and it is deleted after the research concludes. Derived data, including findings and insights, is included in the thesis and publicly shared. The thesis includes methodological descriptions, data analysis results, and a discussion of the findings, ensuring that the research can be reused by other scholars.

Data was securely stored on TU Delft's OneDrive, with clear storage organization to separate personal data from research data. Only the research team, consisting of the student and supervisors, had access to the raw data during the research process. After transcription, interview recordings were deleted to maintain privacy and minimize data storage.

2.5 Ethical Considerations

Since this research includes human research subjects, ethical considerations need to be taken into account. In order to mitigate potential risks interviewees may face as a result of this research, an HREC (Human Research Ethics Committee) application was submitted to its TU Delft committee members. The application includes a risk assessment and mitigation plan, the (previously described) data management plan and the consent forms with opening statements that were signed by interviewees. By having interviewees sign the informed consent forms, they stated that they are aware of the risks involved in participating, and how their data is handled. The forms are signed by each willing participant, as well as confirmed on tape, and then saved onto OneDrive.

The risk assessment and mitigation plan for this research identifies several potential risks and outlines appropriate strategies to address them. One key risk is the potential for participant re-identification, given the small number of bio-based insulation manufacturers. To mitigate this, careful anonymization of interview data is prioritized, ensuring that company names, locations, and other identifiable information are not disclosed in the final analysis. The interviews are conducted online using Microsoft Teams, which is a platform recommended by TU Delft for secure communication. Additionally, to further safeguard participants' privacy, transcripts are reviewed by participants to ensure no sensitive information is inadvertently disclosed. Acknowledging the risk of hacking or eavesdropping during online interviews, measures such as using headphones and ensuring a private environment will be implemented. The final data will be securely stored and handled, and access will be limited to only those directly involved in the research, ensuring compliance with TU Delft's data management and privacy protocols. This research has received HREC approval, meaning all procedures have been followed in accordance with the ethical guidelines.

3 Literature Study

In order to answer the sub-questions formulated in section 1.4, the scientific background must be explored first. In this section first the background of Bio-based Insulation Materials are explored. Secondly, knowing which BBIM are, or have the potential to be, used in housing renovation projects together with identifying a stakeholder focus may provide insight into accompanying barriers and drivers. Finally, the scientific background of systemic innovation in the AEC industry is developed. This all should provide insight into the current status of BBIM manufacture for renovation of existing housing stock in the Netherlands, which can then be used as input for interviews with the defined stakeholders.

3.1 Bio-based Materials

In the introduction, it was mentioned that the Dutch government wishes to phase out fossil fuels for heating and cooling of buildings by decreasing energy use, optimising existing facilities, improving heat insulation, providing renewable energy generation and using or switching to fossil-gas-free and efficient appliances (Ministerie van VRO, 2022). By renovating existing housing stock all these points can be improved upon. Increasing heat insulation may automatically decrease energy use by lowering heating and cooling needs. Using BBBM is appealing as the materials contribute to circular economies in the AEC industry, as well as contributing to the limitation and embodiment of greenhouse gasses. Even though Haisma, Den Boer, Rohmer, and Schouten (2023) argue that replacing conventional building materials with BBBM can, at best, reduce the greenhouse impact by 'only' 18%, this is still significant enough to partly reduce the climate impact of the AEC industry.

Various BBIM can have differing barriers and drivers as to their application. This research focuses on locally growable, plant-based BBM, since it is assumed that these materials have the least impact on the environment concerning CO_2 emissions. It is important to know which materials there are and which have future potential, so differentiation can be made between better and lesser known BBIM. For this, there is first a brief history of BBBM in a general context, followed by an inventory of existing and potential BBIM, and lastly an overview of how BBIM can be used in housing renovation projects.

3.1.1 Conventional Bio-based Building Materials

As previously mentioned, bio-based building materials are building materials made from animal material or from fungi, plants and bacteria that are ecologically grown, harvested, used and reused (Ministerie van BZK, 2023). Because of their availability, versatility, relative ease of use, and sustainability, bio-based materials have been used extensively throughout human history (Jones, 2017). From Jones and Brischke (2017), six main BBBM can be identified in construction history: wood, straw, flax, bamboo, reed and grass. Although these materials have many uses outside of the AEC industry, the focus in this section lies on the (historical) construction applications.

One of the most wide-spread BBBM is wood. Wood has been used as a construction material for centuries. It has been continuously used, with a decrease during the industrial revolution, being replaced by steel constructions (Popescu, 2017). Nowadays, wood can be used in various aspects of construction, such as structure, finishing and furnishing. Solid wood, for example, can be used for timber frame construction, log buildings, foundations, roofing and many other applications. Since the 1980s cross-laminated timber (CLT) has been in use, which enables the strengthening of lower-quality timber, by glueing layers of timber plates perpendicular to each other (Popescu, 2017). CLT has gained popularity due to its ability for automatization, making the process from design to construction more streamlined and therefore quicker. This also made prefabrication and panelization with wood easier. Additionally, the ability to store large quantities of CO_2 increases the appeal of using CLT constructions (Popescu, 2017). Due to high demand and therefore high prices, CLT became a replacement for steel for high construction projects, as CLT made it possible to build higher than ever before using wood (Popescu, 2017). Other products of wood, such as plywood, particle board, oriented strand board and fibreboard, are created with smaller parts of wood glued together, which decreases structural strength, making it suitable for furnishing and interior finishing (Popescu, 2017). For wood construction, European conifers are well suited to use for the various, previously mentioned applications (Popescu, 2017).

Recently, use of straw for construction and insulation has also increased in popularity. Historically, straw has been used as roofing as well as load-bearing wall construction for centuries (Koh & Kraniotis, 2020). Straw is a by-product of cereal crops, and in Europe it is mainly derived from wheat (Walker, Thomson, & Maskell, 2017). Originally, straw has had various applications: as roofing, as an additive to earthen construction materials and as floor covering (Walker, Thomson, & Maskell, 2017). More recently, it has been used as insulation in compression or bale form (Walker, Thomson, & Maskell, 2017). Due to high compression strength, straw can be used as load-bearing, but it is also frequently used as non-loadbearing cast-in-place or in prefabricated panels (Walker, Thomson, & Maskell, 2017).

Flax is one of the oldest known textile fibres, anciently used as fibre for linen cloth (Réh & Barbu, 2017a). The Netherlands counts as a traditional flax country, nowadays using it mainly for apparel and home styling (Réh & Barbu, 2017a). Besides this, flaxboard is created from residual shives pressed together with synthetic adhesives, which can be used for fire-resistance and as general panels in dry or humid (but not wet) conditions (Réh & Barbu, 2017a).

Fibres derived from bamboo can be used as alternatives to wood fibres, although the plant belongs to the grass family (Knapic, Bajraktari & Nunes, 2017). It is one of the fastest growing plants globally, and its strength and stiffness enable its use as a construction material, for example in form of bahareque walls (Knapic, Bajraktari & Nunes, 2017). Bamboo fibres are often used as reinforcement in composite materials, even though extraction of straight and fine fibres is difficult (Knapic, Bajraktari & Nunes, 2017).

Reed has been used as roofing for centuries, due to its light weight, flexibility, availability and insulation properties (Greef & Brischke, 2017; Malheiro et al., 2021). Despite its long-standing use in roofing, recent reports of premature failures due to moisture absorption highlight challenges in reed's application as a sustainable building material (Greef & Brischke, 2017). This is mainly caused by the reed absorbing moisture, which then leads to decay of the underlying structure (Greef & Brischke, 2017). Differences have been observed between reeds of varying origin and processing (Greef & Brischke, 2017).

Grass mats have been used as insulation in traveling coaches and later in housing walls (Teppand, 2017). Specifically hay has historically been used in humid climates as temporary insulation during autumn and winter by spreading it on attic floors (Teppand, 2017). However, there are better (natural) alternatives. Due to hay having inconsistent quality, its insulation value is also inconsistent (Enviroliteracy Team, 2025). Untreated, it absorbs moisture readily, which diminishes its insulating effectiveness and can promote mould growth, it attracts rodents (Enviroliteracy Team, 2025). Other grasses, however, have shown sufficiently good properties to be comparable to mineral insulation materials (Teppand, 2017).

In the past, of these six materials, only flax, reed and grasses have been used as insulation materials without enhancements or additives. Nowadays, taking CO_2 emissions into account, untreated BBIM could be interesting alternatives to CIM.

While, of these six materials, only flax, reed, and other grasses have historically been the primary BBM used as insulation, recent research and innovation have broadened the scope of BBIM. As research into BBIM has advanced, the scope has expanded to include the other described historical materials (wood, straw, and bamboo), which were not originally considered for insulation purposes. Furthermore, newer developments have introduced additional plant-based materials, such as miscanthus and hemp for their potential to contribute to more sustainable building practices. This expansion is driven by growing recognition of the environmental benefits of BBIM, especially their role in reducing CO_2 emissions. As the demand for environmentally friendly alternatives to CIM grows, continued exploration into the properties and potential of these BBIM will be crucial in advancing sustainable building practices, particularly in housing renovation projects.

3.1.2 Bio-based Insulation Materials

Following the exploration of various BBBM and their historical and modern uses, it is necessary to assess the properties of these materials, particularly in relation to their role as insulation. For BBIM to compete with CIM, it is crucial to understand their performance characteristics, including insulation value, vapour permeability, and the required thickness for effective thermal performance. These properties play a significant role in determining the suitability of BBIM for various construction applications, particularly in the context of housing renovation. To evaluate these materials, a selection is made based on their potential for sustainable performance and their ability to meet the demands of modern building standards. In the following section, the properties of several (potential) BBIM are compared to CIM, exploring their advantages and limitations in achieving energy efficiency and environmental sustainability.

Currently, several European manufacturers produce BBIM that are available on the Dutch market. The Nationale Milieudatabase (NMD) currently contains 42 BBIM manufactured by Dutch companies (Ministerie van VRO, 2025b). As shown in Figure 5, these include flexible batts made from materials such as (from top to bottom) grass fibres, flax, hemp, cellulose, wood fibre, and (recycled) cotton (De Isolatieshop, n.d.-a). Although batts are more frequently used, wood fibre, straw or cellulose can also be blown-in (Van der Waal, 2024). For this research, the focus lies with locally grown, plant-based BBIM, as materials that are animal-based or imported are likely to result in higher CO_2 emissions. The Dutch government concentrates on flax, hemp fibre and miscanthus (De Jonge et al., 2023) (bast fibres), which is also the focus of this research, alongside reed and straw (grasses). Although other materials also show promise, they are excluded from this study. The materials are chosen due to their suitability to be grown in the Netherlands, their short growing time and high performance (potential).

Figure 5 – Flexible insulation batts made from BBM, sold in Dutch market (own work, based on De Isolatieshop, n.d.-a)

The selected materials (in bold), as well as other BBIM and CIM are compared in Table 1, which provides an overview of the following properties:

- the λ shows thermal conductivity, a lower value requires less thickness of the material for sufficient thermal insulation,
- A lower vapour diffusion means the material is more permeable,
- A1 is the best fire classification and F is the worst,
- A longer phase shift is more favourable since this means more consistent temperatures,
- Lastly, the MKI (Milieukostenindicator) reflects the environmental cost of production (kiwa, n.d.), where a lower score means the material is less environmentally damaging.

Table 1 shows that BBIM generally need more thickness to achieve the same thermal insulation value, as well as performing lower on fire classification compared to CIM. On the other hand, BBIM show, on average, better vapour diffusion and they have longer phase shifts. On top of this, BBIM outperform CIM significantly when looking a the MKI. Where cells are empty no reliable information could be found, and no fire certification means that a product receives an F by default. While the data in this table attempts to include as many ranges as possible, it may differ from products of the same material.

In recent years, the AEC industry has moved away from impermeable vapour barriers to building vapour penetrable structures. A household produces, on average, 10L of vapour per day (Isoleerbewust, 2023). By constructing vapour-permeable structures a build-up of vapours can move from inside the house to the outside, preventing the forming of mould (Isoleerbewust, 2023). Bio-based insulation materials are inherently vapour permeable, as opposed to fossil-based insulation materials (FBIM) such as XPS, EPS, PIR and PUR, which are vapour proof (Table 1) (OnderhoudNL & Building Balance, 2024). Stone and glass wool are also vapour permeable, but construction methods up to the present time have not made use of this attribute (OnderhoudNL & Building Balance, 2024). However, the use of vapour-permeable façades in the Netherlands has faced criticism. Some argue that their effectiveness remains unproven in the Dutch climate, where winters are wet and temperate, unlike Scandinavia's dry, cold winters. In the Netherlands, up to 98% of vapours would need to be discharged mechanically (Knauf, 2024). Despite this, Dutch collectives continue to promote vapour-permeability, believing that it leads to a healthier indoor environment with more stable humidity levels (Isoleerbewust, 2023; OnderhoudNL & Building Balance, 2024). Additionally, BBIM's natural moisture-transporting properties help prevent mould formation. To maximize these benefits, however, vapour-permeable foil and finishes, such as loam plaster (rather than latex paint), are recommended to ensure sufficient ventilation (Van Der Waal, 2024; Isoleerbewust, 2023).

Material	λ (W/m*K)	Thickness for Rd=3,5 (m) (own calculation)	Vapour diffusion (μ)	Fire Classification (DIN EN 13501-1)	Thermal Phase Shift (φ, 200 mm)(hrs)	Av. MKI (€)	
						A1	A2
EPS	0.030[1]	0.11	20-100[1]	C[1]		0.69[10]	1.22[10]
Glass wool	0.032[1]	0.11	1[1]	A1[1]	3.3[11]	0.67[10]	-
PUR/PIR	0.023[1]	0.08	50-100[1]	B[1]	3.9[11]	1.82[10]	-
Stone wool	0.035[1]	0.12	1-5[1]	A1[1]	4.7[11]	0.77[10]	-
XPS	0.032[1]	0.08	150-300[1]	B[1]		3.24[10]	-
Bamboo	0.057[a, 2]	0.20	12-15.4[a, 2]	F (by default)		-	
Cellulose	0.038-0.042[3, 4]	0.15	1-3[3, 4]	C-E[4]	7.7[11]	0.29[10]	0.12[10]
Cork	0.040-0.044[3, 5, 6]	0.15	5-10[6]	E[6]		0.70[10]	2.87[10]
Cotton	0.039[4, 7]	0.14	1-2[4]	E[4]	3.9[11]	0.44[10]	0.64[10]
Flax	**0.039**[3, 4, 6, 7]	**0.14**	**1-2**[4, 6, 7]	**C**[4]	**4.3**[11]	**0.09**[10]	**0.15**[10]
Hemp	**0.038-0.050**[3, 4, 5, 6]	**0.13**	**1-2**[4, 6]	**B-E**[4, 6]	**6.7**[11]	**0.16**[10]	**0.23**[10]
Miscanthus	**0.059**[8, b]	**0.21**	**unknown**	**F (by default)**		**0.08**[10]	**0.07**[10]
Reed	**0.045-0.065**[3, 4, 9]	**0.23**	**2**[4, 9]	**E**[4, 9]		**-**	
Straw	**0.046-0.052**[3, 4, 5]	**0.18**	**2**[3]	**E**[4, 6]	**9.2**[11]	**0.17**[10]	**0.14**[10]
Wood fibres	0.035-0.038[3, 4, 5]	0.13	1-10[3, 4]	E[4, 6]	7.5[11]	0.16[10]	0.22[10]

Table 1 – Insulation material properties (own work, based on references in footnote) [*]

The overview in Table 1 shows that Miscanthus specifically is not sufficiently developed yet to compete with other insulation materials. It takes two to three years to grow before it can be harvested annually for 15 to 20 years. This delayed return on investment makes it difficult for farmers to switch crops without substantial financial backing or guaranteed demand (Helle, 2024; Miscanthusgroep.nl, n.d.). Because of the long wait before it becomes profitable, many farmers don't have the financial flexibility to make the switch, even though miscanthus becomes a consistent, yearly harvest after that initial period (Helle, 2024; Miscanthusgroep.nl, n.d.). On the upside, once established, miscanthus requires little maintenance, earning it the nickname "pension grass" (A. Eindhoven, Supply Chain Manager at Building Balance, personal communication, April 16, 2025). Its high yield (four times that of hemp) makes it appealing, especially since it can be easily scaled in factories. It also offers a variety of products, including cellulose (for blow-in insulation), lignin (as a bitumen substitute in asphalt), and vanilla extract (used in the food industry). However, strict regulations are needed when planting miscanthus to avoid monocultures and preserve the diversity of the Dutch landscape (A. Eindhoven, personal communication, April 16, 2025). So,

[*][1] De Isolatieshop, n.d.-b
[2] Nguyen et al., 2017
[3] Künzel, 2022
[4] Mulder, Suidman & Spaak Circular Solutions B.V., 2023
[5] Cosentino, Fernandes & Mateus, 2023
[6] FNR et al., 2024
[7] De Isolatieshop, n.d.-a
[8] Personal communication via TBI, n.d.
[9] Aza-Medina et al., 2023
[10] Stichting Nationale Milieudatabase (n.d.-b)
[11] Van Der Waal, 2024, for a thickness of 18 cm
[a] Higher glue content increases mechanical strength but reduces moisture buffering and insulation performance
[b] Can be used as blow-in insulation, λ is tested at 0.057 in lab, 0.059 outside of it

while Miscanthus is currently not a feasible BBIM, it shows potential to become one of the most favourable BBIM over time. Therefore it is also included as a (potential) BBIM in this thesis.

Flax and hemp perform relatively similarly to CIM on thermal conductivity and fire classification (Table 1). Both materials have lower vapour diffusion than FBIM, but hemp does especially well on thermal phase shift. Both BBIM have lower MKIs than CIM. Hemp shows high promise to replace glass fibre insulation, as it is relatively cheap, easy to process, has consistent quality and it weighs little (Réh & Barbu, 2017b). Reed and straw perform comparatively poorer than CIM, especially regarding thermal conductivity and fire classification, but they both do well on vapour diffusion, and straw scores extraordinarily well on thermal phase shift, as well as having a favourable MKI (Table 1).

This thesis disregards (1) wood, (2) (recycled) cellulose, (3) bamboo, (4) mycelium, (5) cork, and (6) cotton for expansion in the Netherlands. While *(1 & 2) wood and (recycled) cellulose* insulation have been in production for more the 20 years (GUTEX, n.d.; ISOCELL, n.d.; STEICO, n.d.), these materials are excluded. Cellulose is, for the moment, mainly derived from cotton and wood (Bakri, Rahman & Chowdhury, 2022; Jones & Brischke, 2017), which are both unsuitable for widespread cultivation in the Netherlands. Additionally, *(2) recycled materials* are excluded because the process of creating insulation out of such material brings different barriers and drivers than a production chain from newly grown BBM. While recycled materials can also offer environmental benefits, the primary aim here is to explore the potential of newly produced materials that are sustainably grown and harvested in the Netherlands. Even though *(3) bamboo* is plant-based and can be grown rapidly and on Dutch soil (NOS, 2024), research on the application of bamboo insulation materials shows that there are better alternatives. Bamboo insulation can, at best, achieve a thermal conductivity of 0.057 W/mK, which is one of the least favourable compared to other analysed BBIM (Table 1). Additionally, the conductivity worsens when the bamboo insulation gets damp (Nguyen, Grillet, Diep, Thuc & Woloszyn, 2017), but building vapour proof by adding glues, for example, would take away the advantages gained with permeability. *(4) Mycelium*-based insulation materials, while innovative and showing potential for future applications, are excluded from this research due to their current limited scalability and availability. At this stage, mycelium is still largely in the experimental or niche market phase, and not yet comparable to more established, locally growable plant-based materials in terms of production volume and practical use in housing renovation (interview participant). The Dutch climate is sub-optimal for the cultivation of *(5&6) cork and cotton*, meaning they are excluded as well.

BBIM show significant promise for application in housing renovation projects due to their moisture-regulating properties and low environmental impact. Materials such as hemp, flax, reed, and straw are particularly suited for Dutch-grown applications, offering sustainable alternatives to conventional insulation materials. While BBIM generally require more thickness for equivalent thermal performance and face challenges in fire classification, their vapour diffusion and phase shift properties provide distinct advantages. Although Miscanthus is not yet fully developed for large-scale use, its potential for high yield and diverse applications suggests it could become a competitive BBIM in the future. Strategic choices regarding suitable renovation methods and careful consideration of material properties are essential for maximizing the benefits of BBIM in the Dutch housing stock.

3.1.3 Bio-based Insulation Materials in Renovation

According to CBS (2024a), the Dutch housing stock consists mostly of dwellings built before 1945 and between the years of 1965 – 1995. Additionally, the largest stock consists of terraced houses and multi-family houses (CBS, 2024b) such as tenement houses, houses with balcony access, maisonettes, apartment buildings, garden flats and upstairs apartments. From this and from research by the RVO (Rijksdienst voor Ondernemend Nederland) (2022) it can be concluded that the current Dutch housing stock consists largely of terraced houses and multi-family houses built before 1945 or between 1965-1995. Housing of this typology from these times generally have some measures towards making them more sustainable, however, insulation of (ground) floors, façades and flat roofs has largely not happened yet, or is of insufficient quality (RVO, 2022, pp. 52, 56, 58, 112, 116,118).

How to insulate in renovation depends on the location of the intervention. The following overview outlines the main techniques for different parts of the building (Holland Houtland, 2024; Isoleerbewust, 2023):

1. **Slanted roof**: Insulation can be applied on the inside, in between wooden beams, or from the outside. Insulating from the inside is typically the most cost-effective option, using flexible batts placed between existing beams. External insulation is more suited when the roof is being

replaced, utilizing denser materials like wood fibre panels. If the attic is unused, insulating the attic floor instead of the slanted roof is also an option.

2. **Flat roof**: Insulation is generally applied externally. This can be done by replacing the entire roof structure with high-density materials such as wood fibre panels, or by layering BBIM, like expanded cork, on top of the existing structure. Internal insulation is possible, but discouraged, due to mould risks and is therefore typically only considered for smaller surfaces.
3. **Intermediate floor** (in case of attic): These are insulated by placing flexible batts between existing construction beams.
4. **Façade**: Insulation can be added by filling cavity walls, applying materials on the inside, or covering the exterior. If available, filling the cavity wall is the most suitable way of adding insulation to a façade. In the Netherlands, the added insulation must be able to withstand high moisture levels when inserted in the cavity wall, therefore materials such as cork and cellulose are suitable materials. When insulating façades on the outside, solid materials need to be used, such as cork. BBIM need more thickness than CIM for the same insulation value, therefore insulating on the inside is sometimes not an option. When insulating on the inside, a cavity wall or other interventions are necessary to allow sufficient ventilation.
5. **Ground floor**: Insulation can be applied on top, from below, or underneath. Ideally, solid materials like wood fibre panels are installed under wooden floors, or flexible batts beneath concrete floors in crawl spaces. If the crawl space is too small, wood fibre panels may be added on top, although this provides limitations in height because of doors, thresholds and skirting boards. An alternative for (very) moist crawl spaces is insulating the soil itself with, for example, shells.

		Wood Fibre	Cork	Grass	**Flax**	**Hemp**	Cellulose	(Recycled) Cotton	**Miscanthus**	**Straw**	Shells
Slanted Roof	Inside			x	x	x	x	x	x	x	
	Outside	x									
Flat Roof	Inside			x	x	x	x	x	x	x	
	Outside	x	x								
Intermediate Floor	In between construction	x		x	x	x	x	x	x	x	
Façade	Cavity		x				x				
	Inside	x	x	x	x	x	x	x	x	x	
	Outside		x								
Ground Floor	Top	x	x								
	Below	x		x	x	x	x	x	x	x	
	Underneath										x

Table 2 – Material use per renovation intervention (own work, based on Holland Houtland (2024) and Isoleerbewust, 2023)

The suitability of BBIM for each renovation method is outlined in Table 2. From the analysis, it is clear that inside insulation is the most compatible application for the selected BBIM. For slanted roofs, intermediate floors, and ground floors, this method is recommended. It is possible for façades as well, though discouraged for flat roofs (Holland Houtland, 2024; Isoleerbewust, 2023). This means that flax, hemp, (potentially) miscanthus, reed and straw are suitable for all but flat roof insulation (Table 2), for which other, not locally growable, BBIM can be applied.

One promising application of BBIM in renovation is hempcrete, or hemplime, frequently cited for its strong insulating properties and moisture regulation (Holland Houtland, 2024; Isoleerbewust, 2023). Hempcrete is a biocomposite of hemp and lime, offering both thermal insulation and moisture buffering. However, it is not compostable, which may limit its environmental advantages compared to fully plant-based BBIM. Additionally, renovation projects often face challenges due to undocumented modifications to building structures, complicating the implementation of vapour-permeable materials unless the existing conditions are well understood.

As mentioned previously, BBIM are generally vapour-permeable, and could offer healthier indoor climates, if applied correctly. Claude, Nguyen, Delhaye, Mayeux and Charron (2023) examined the hygroscopic and thermal behaviour of BBIM in wood-frame walls. Their findings revealed that the moisture-buffering effect depends largely on the composition of the wall structure. They recommend combining BBIM with clay boards or adjust the thickness of interior finishes like plaster or clay, for optimal thermal inertia and summer comfort (Claude et al., 2023).

BBIM generally remains more expensive than CIM. According to Van der Waal (2024), BBIM batts are priced between 1.5 to 3 times higher than CIM, while bio-based blow-in insulation is actually cheaper. However, due to ease of installation and reduced disruption for occupants, renovation projects often prefer batts despite the higher cost. From this it could be argued that Straw-based blow-in insulation is recommended due to its affordability and quick installation time, whereas batts can be a practical alternative when specialized skills and equipment for blow-in methods are unavailable.

Furthermore, recent projects like Wonion's sustainable housing renovation initiative demonstrate that BBIM can be effectively integrated into large-scale housing projects (Rebergen, 2023). Wonion successfully applied BBIM in multi-family homes, achieving significant energy savings while also enhancing indoor comfort. This project serves as a practical example of how policy support, technical expertise, and material innovation can converge to make bio-based renovations feasible and impactful.

Overall, flax, hemp, miscanthus, reed and straw are all suitable options for renovation on the inside, using batts. Currently, these insulation batts are more expensive than CIM, however. Therefore, straw blow-in insulation could be a quick and cost-effective alternative, if this did not require specialised knowledge and equipment. While BBIM offer promising solutions for enhancing thermal performance and sustainability, their higher costs and application method remain significant challenges.

3.1.4 Conclusion

The exploration of BBIM has demonstrated their potential as sustainable alternatives for the Dutch renovation sector. While historically limited to materials like flax and reed, modern innovations have introduced hemp, straw, and Miscanthus as viable insulation options. With lower carbon emissions, improved moisture regulation, and contributions to circular building practices, these materials align well with both national and European climate goals. Although BBIM generally require greater thickness than CIM and come with higher costs, their favourable environmental impact and local growability make them promising alternatives. Straw-based blow-in insulation, in particular, presents a quick and cost-effective solution, though it is hindered by the need for specialised knowledge and equipment. Strategic choices regarding suitable renovation methods and careful consideration of material properties are crucial for maximizing the benefits of BBIM in the Dutch housing stock. Therefore, it can be advised to currently focus on batts made out of flax, hemp, reed and straw, and to eventually further expand towards flexible batts made out of miscanthus, and blow-in insulation from straw.

3.2 Barriers and Drivers

Understanding how the BBIM discussed in the previous section can be successfully scaled up for renovation projects requires addressing existing barriers and leveraging key drivers. The following sections delve deeper into the systemic challenges faced by BBIM manufacturers, exploring cost implications, quality assurance and knowledge gaps. These insights inform strategic recommendations for enhancing the production and adoption of BBIM in the Netherlands, contributing to a more sustainable built environment.

As mentioned, in recent years, the Dutch construction industry has shown growing interest in BBIM, especially with the push towards sustainability and circular building. Currently, wood makes up just 2%, and other bio-based building materials only 0.1%, of all construction materials used in the Netherlands by weight (NIBE, 2019). Since the aim of using BBIM is to decrease the ecological footprint of the AEC industry, applying BBIM in combination with wood is favourable (Blommaert et al., 2024). And while demand for these materials is increasing, and more raw BBM are being cultivated, the actual supply of BBIM products has not grown much (De Jonge et al., 2023). This suggests that the bottleneck lies in the production process, more specifically, in manufacturing. In the Netherlands, manufacturers and suppliers are often the same company when it comes to BBIM. While there are external suppliers, most of the time the company that processes the raw material also sells it. Because manufacturers usually focus on processing just one type of raw material, choosing a specific BBIM therefore often also means choosing a specific manufacturer.

In AEC projects, material selection, and by extension, manufacturer selection, is generally based on three main goals: reducing purchase risk, getting the best value for money, and building long-term working relationships (Taherdoost & Brard, 2019). This means that manufacturers need to create awareness about, and trust in, their products and their own abilities. They need to assure their partners that their BBIM are high quality, are worth the (current) higher prices and that the manufacturer will deliver what they say. Since using BBIM is not required in most building projects, these products need to score well to be preferred over CIM.

Figure 6 – Innovation Barriers in the AEC industry (own work)

In general, when it comes to innovation in the AEC industry, three key barriers can be identified (Figure 6): Cost, Quality Assurance, and Knowledge (De Jonge et al., 2023; Koster et al., 2020; NIBE, 2019). This means that, on top of creating trust, manufacturers face risks and high costs themselves, when starting the production of BBIM. This choice is not only based on the upfront price of a material, but also on broader value considerations: the total cost of ownership (TCO). TCO includes "the total of the present value of all direct, indirect, recurring, and nonrecurring costs incurred or estimated to be incurred in the design, development, production, operation, maintenance, and renewal of a facility, structure, or asset over its anticipated life span." (Christensen, 2016, p. 21). Quality assurance refers to consistent product performance and meeting legal and technical standards. Knowledge covers both technical expertise in how to process and apply BBIM, and awareness about their availability and potential.

At the same time, there are drivers that support BBIM production, such as policy support and market interest in greener products. These conditions are often shaped by wider trends in the construction sector. Le et al. (2025), for example, identify the three most influential drivers for the adoption of circular bio-based building materials as the proven long-term quality of materials, their cost-effectiveness, and the availability of reliable information. These findings closely mirror the main barriers explored in this chapter (cost, quality assurance, and knowledge), suggesting that efforts to stimulate BBIM production must address these aspects directly. Understanding the manufacturer's role in the supply chain can help identify where the biggest challenges lie, and where the best opportunities for growth might be.

The aim of this section is to explore the current limitations and opportunities in scaling up the production of BBIM in the Netherlands. By focusing on manufacturers, who play a central role in turning raw materials into usable products, this section seeks to understand the key barriers they face, as well as the conditions that can help them grow. This perspective is important because, without addressing supply-side challenges, the wider adoption of BBIM will remain limited, no matter how strong the demand or policy support. The remainder of this section is structured around five key themes that together shape the current landscape for BBIM manufacturing. It begins with a closer look at the manufacturer's role within the broader stakeholder environment, followed by an exploration of cost-related challenges such as investment risk and pricing. Next, the section discusses how quality assurance is managed in the sector, and how knowledge and expertise affect both production and market adoption. Finally, the chapter outlines the main drivers that are currently supporting or accelerating BBIM production in the Netherlands.

3.2.1 Stakeholder focus

This section expands on the research focus on manufacturers. It explains their role among and interactions with other stakeholders. Stakeholders are defined as “those actors which will incur – or perceive they will incur – a direct benefit or loss as a result of the project” (Winch, 2010, p. 74). In the context of AEC projects, stakeholders can be grouped into the following categories (Milind & Arti, 2024):

Figure 7 – Stakeholder categories (own work, based on Milind & Arti, 2024)

Among these, this research focuses on (insulation) manufacturers, as they represent a key bottleneck in the adoption of BBIM in the Netherlands. As mentioned previously, while demand for BBIM is growing and sustainability goals are aligning across the sector, the pace of manufacturing has not kept up, limiting availability and scalability.

However, manufacturers do not operate in isolation. Their actions are influenced by upstream and downstream stakeholders. For instance, clients, architects and contractors can specify or request the use of BBIM, while policymakers and regulators can create enabling conditions through subsidies or procurement criteria. Conversely, manufacturers can drive innovation by developing new products, engaging in partnerships, and educating the market. This interdependency underlines the importance of collaboration across the construction value chain. As noted by Winch (2010), project success increasingly depends on integrated teamwork among all actors. Chao-Duivis. Koning and Ubbink (2013) similarly emphasize the central role of the design-build team in aligning interests and facilitating cooperation. By focusing on manufacturers within this interconnected system, this research aims to understand how their position, challenges, and potential for collaboration can be leveraged to accelerate the uptake of BBIM in housing renovation projects.

3.2.2 Cost

Cost remains a significant barrier to the broader adoption of BBIM in the Dutch renovation market. Compared to conventional insulation materials, BBIM are often more expensive due to higher production costs, limited economies of scale, and the need for specialized processing. Currently, insulating with conventional materials costs on average €10/m^2, approximately 30% less than bio-based alternatives (Isoleerbewust, 2023). Given that material costs can constitute up to 50% of total construction expenses (Taherdoost & Brard, 2019), this price gap can discourage architects, contractors, and clients from specifying BBIM, which in turn impacts demand signals to manufacturers. On top of this, while BBIM offer long-term benefits, such as reduced embodied carbon, improved indoor air quality, and moisture-regulating properties, these advantages are often undervalued in procurement processes that prioritize immediate costs over lifecycle value. A more integrated approach, based on the TCO, would take into account not only the initial purchase price, but also performance over time, maintenance needs, health impacts, and end-of-life scenarios (Christensen, 2016). Without this perspective, the broader value that BBIM can deliver across a building’s lifespan is easily overlooked. This short-term focus can overshadow the potential for BBIM to contribute to healthier living environments and long-term energy savings.

Beyond material pricing, BBIM manufacturers face substantial capital investment challenges. Establishing or upgrading production facilities to accommodate bio-based materials requires significant upfront costs for specialized machinery, securing consistent raw material supplies, and obtaining necessary certifications. For small or emerging manufacturers, access to financing is often limited, especially in a market where future demand remains uncertain. This financial hurdle contributes to a cautious approach toward scaling production, even as sustainability goals become more prominent.

Internationally, some countries have implemented financial mechanisms to mitigate these challenges. In Germany, for example, subsidies have been provided to cover up to 50% of the additional costs associated with BBIM. This support has led to a fiftyfold increase in the market volume of such products over two decades, demonstrating the effectiveness of targeted financial incentives (Le Pierrès, Grimault, & Bellassen, 2023). Similarly, France has incorporated the promotion of long-life wood products, including insulation materials, into its National Low-Carbon Strategy, aiming to redirect wood use toward applications that store carbon over extended periods (Le Pierrès, Grimault, & Bellassen, 2023). In contrast, the Netherlands lacks sufficiently attractive subsidies for BBIM, placing domestic manufacturers at a relative disadvantage in scaling up production and reducing unit costs.

While there are some support mechanisms for circular and bio-based building in the Netherlands, there is insufficient incentive to invest in new or expanded processing facilities in order to create BBIM (De Jonge et al., 2023). For manufacturers, setting up or converting production lines for BBIM involves significant upfront investment, often without a clear guarantee of profitability due to fluctuating demand and limited long-term policy support. This absence hinders the scaling up of production and the ability to reduce costs over time.

Addressing the cost challenge will require coordinated action across the value chain. From a manufacturer's perspective, stronger demand signals, supportive policies, and investment in scalable processing infrastructure are all crucial to bring down production costs and close the price gap. Only then can bio-based insulation become a competitive and attractive option in the mainstream renovation market.

3.2.3 Quality assurance

Quality assurance is a critical factor in the adoption of BBIM, particularly in a sector where building materials must consistently meet strict performance, safety, and environmental standards. From a manufacturer's perspective, ensuring product reliability and compliance is essential to gaining trust across the construction value chain, from architects and contractors to clients and regulatory bodies.

However, BBIM currently face several challenges when it comes to quality assurance. In practical terms (as shown in section 3.1), BBIM typically require a greater material volume to achieve the same thermal performance as conventional alternatives. This can raise concerns about space efficiency and logistics, particularly in renovation projects with limited wall cavity space. Manufacturers must therefore ensure that their products are not only sustainable, but also meet performance expectations regarding thermal resistance, fire safety, moisture behaviour, and long-term durability. On top of this, unlike conventional insulation materials, BBIMs such as hemp, flax, or straw are derived from natural sources, which can lead to variations in fibre composition, density, and moisture content. These inconsistencies can affect the thermal conductivity and moisture resistance of the final product, making it difficult to guarantee consistent performance across different batches.

Environmental performance indicators have also become increasingly important. Although not mandatory (Ecomatters, 2024), Dutch manufacturers are increasingly expected to provide clear data on Life Cycle Assessments (LCAs), Environmental Product Declarations (EPDs), and the Dutch MilieuKostenIndicator (MKI), which evaluates the environmental cost of building products (kiwa, n.d.). The Dutch calculation method for environmental performance is more comprehensive than many others used in Europe, incorporating additional impact categories and stricter data requirements. Consequently, LCAs from other European countries are often not accepted in the Netherlands, as they lack key indicators required by the NMD. This creates an asymmetrical situation: Dutch LCAs are generally accepted abroad, but international LCAs are not automatically valid within the Dutch system (Stichting Nationale Milieudatabase, n.d.-a). This places an extra burden on both foreign and domestic manufacturers, who must often invest in new assessments specifically tailored to the Dutch methodology. So, while these tools offer transparency, they also require manufacturers to invest in independent testing and documentation, which can be time-consuming and costly, especially for smaller or newer companies.

Beyond environmental indicators, formal certification remains essential. Existing legislation and building codes are often designed around CIM, making it difficult for BBIM to fit within established frameworks (TNO, 2024). As a result, it can be argued that there is still insufficient formal quality control and standardization for BBIM (De Jonge et al., 2023). This regulatory mismatch not only complicates certification and product development but can also discourage manufacturers from investing in large-scale production. In the Netherlands, key certifications include KOMO (technical quality, lawfully optional but often required in practice) (KOMO,n.d.), CE marking (compliance with EU product standards), and DUBOkeur (sustainability) (NIBE,2021). In neighbouring countries, different systems apply. While the natureplus certification is officially recognized across Europe, its actual uptake appears to be most prominent in Germany (where it originated), Austria, and Switzerland, where ecological building practices are more established (Natureplus Institute, n.d.). It includes strict criteria on environmental performance, health impacts, and indoor air quality, including compliance with AgBB (Ausschus zur gesundheitlichen Bewertung von Bauprodukten, or Committee for the health assessment of construction products) emission standards (Umweltbundesamt, 2024). In Belgium, environmental performance is typically demonstrated through the national B-EPD system (FPS Health, Food Chain Safety and Environment, 2025), linked to the federal TOTEM tool (Tool to Optimise the Total Environmental impact of Materials) (De Jaegher et al., 2022), which supports life cycle-based material selection in construction. This is to illustrate, that while these systems serve similar purposes, their criteria, scope, and market recognition vary, complicating cross-border expansion for manufacturers and creating uncertainty about which certifications are most influential in each national context. On top of this, certifications also strongly influence professional decision-making. Many architects, developers, and municipalities rely on certified labels to assess product reliability, sustainability, and suitability for government-backed projects. A lack of recognized certification may therefore prevent BBIM from being selected, regardless of their actual performance. For manufacturers, obtaining and maintaining certification is not only a regulatory hurdle but also a strategic tool for building credibility and market share (Ministeries van IenW, BZK, SZW, EZ, BZ & OCW, 2022).

In short, improving quality assurance for BBIM is essential for their broader acceptance in the renovation of the Dutch housing stock. Manufacturers face challenges not only in guaranteeing (consistent) product performance due to the inherent properties of raw materials, but also in navigating a demanding regulatory environment. Meeting expectations around environmental transparency, through instruments such as LCAs, EPDs, and MKI scores, requires significant investment in time, expertise, and testing. Additionally, fragmented certification systems and regulatory frameworks create uncertainty and raise the threshold for scaling up production. Addressing these barriers calls for a coordinated effort to align standards, streamline certification processes, and ensure that both technical and environmental performance of BBIM can be verified in a reliable and cost-effective manner.

3.2.4 Knowledge

A lack of knowledge and awareness is a major barrier to the wider adoption of BBIM, both within the construction value chain and among end-users. From a manufacturer's perspective, these knowledge gaps occur at multiple levels: from technical understanding of materials and production processes, to practical know-how on how BBIM can be integrated into renovation projects, and broader awareness of market opportunities.

Jensen, Roberts, and Kedir (2023) identify three core knowledge-related barriers that hinder innovation in the AEC industry, all of which are relevant to BBIM adoption. First, stakeholders often do not know where to find the right products, due to a lack of market transparency and limited visibility of new or alternative building systems. In the context of BBIM, manufacturers frequently struggle to get their products in front of decision-makers, particularly when their materials are not part of standard construction catalogues or procurement frameworks. This is further compounded by limited marketing and communication efforts, which means that even technically sound BBIM products often remain overlooked. Clear product documentation, participation in industry events, and presence on procurement platforms are essential tools for improving visibility, but are not yet widely adopted by all manufacturers.

Second, even when BBIM are known, there are barriers to implementing them effectively (Jensen, Roberts & Kedir, 2023). Poor understanding of how to install or integrate these materials into existing buildings can lead to suboptimal performance. In renovation projects, this is particularly critical: older buildings often have variable wall structures, moisture conditions, or space limitations that require tailored solutions. If builders or clients encounter difficulties, for example, with fitting or moisture sensitivity, it can result in disappointment and rejection of the material altogether. Manufacturers are therefore challenged not only to produce BBIM, but to ensure that sufficient knowledge, documentation, and guidance are available to support their use in practice.

Third, systemic change in the AEC industry requires education at every level (Jensen, Roberts & Kedir, 2023). System change is only possible if all participants understand the broader value of bio-based alternatives. Manufacturers can play an important role here by actively engaging in knowledge dissemination: providing training, collaborating on pilot projects, and developing clear communication on performance, sustainability, and cost.

A clear example of these knowledge barriers can be seen in the case of straw. Despite a significant body of research supporting its technical and environmental suitability, straw-based insulation could be used more widely in practice. According to Koh and Kraniotis (2020), inconsistent information on its material properties contributes to uncertainty among stakeholders. This lack of clarity can discourage both manufacturers and specifiers from investing in its development or selection, particularly in a market like the Netherlands, where unbending regulations and performance requirements create high thresholds.

In short, addressing knowledge barriers requires action on multiple fronts. Manufacturers can lead not only in production but also in education, communication, and collaboration, ensuring that BBIM are visible, understood, and correctly implemented across the Dutch renovation sector.

3.2.5 Drivers

While the adoption of BBIM is hindered by several barriers, there are also significant drivers and opportunities emerging, particularly for manufacturers operating in the Dutch renovation market. These drivers include financial incentives, policy developments, certification tools, supply chain innovations, and evolving market signals that collectively strengthen the business case for BBIM production.

A growing number of subsidies and financial instruments support the application of BBIM in renovation projects, indirectly driving demand and opening up opportunities for manufacturers. The Investment Subsidy for Renewable Energy and Energy Saving (ISDE) allows homeowners to claim support for energy-saving measures such as insulation. Importantly, the ISDE includes a BBIM-specific top-up: up to €6 per m^2 for materials composed of at least 70% bio-based content (Verbeterjehuis, n.d.-b). While this subsidy targets end-users, it sends a clear market signal to manufacturers that BBIM are being prioritized in national sustainability policy. Similarly, the Energiebespaarlening offers low-interest loans to homeowners for sustainable renovation (including insulation), further enhancing affordability and stimulating potential demand for BBIM (Verbeterjehuis, n.d.-a). The Dutch government is also exploring carbon credit systems, whereby the removal or storage of CO_2 could be rewarded financially. Both the EU and the Dutch government are developing frameworks in which carbon credits can be exchanged for subsidies (OnderhoudNL & Building Balance, 2024). This emerging system could create a new economic incentive for manufacturers who use low-emission or carbon-negative raw materials.

The NABB has earmarked €200 million to stimulate the bio-based construction sector (De Jonge et al., 2023). This initiative explicitly includes both material manufacturers and farmers, with the aim of ensuring secure supply chains and consistent material flows. For manufacturers, this represents a major opportunity for scaling up production capacity in alignment with national policy goals. In addition, environmental performance requirements for construction are being tightened, with a focus on CO_2 reduction, which strengthens the regulatory case for BBIM. An example of supply chain integration is seen in the potential of crops like miscanthus. According to Prinsen (2024), this perennial crop is suitable for underutilized farmland near Natura 2000 areas, requires minimal inputs, and offers farmers a low-maintenance income stream. Such developments create opportunities for manufacturers to establish local, circular material supply chains.

Despite these incentives, BBIM products remain underrepresented in official product lists. Analysis of the RVO's approved insulation products list shows that fewer than 5% of the listed products currently qualify for the BBIM-specific ISDE subsidy (RVO, 2024). This indicates a gap between available subsidies and the actual number of compliant BBIM products, posing a barrier to market access for manufacturers. One explanation may lie in the outdated standards used to evaluate building materials. According to TNO (2024), current assessment methods do not fully account for environmental indicators such as CO_2, particulate matter, and nitrogen emissions. Updating these standards would allow BBIM to compete more fairly with conventional materials (especially on environmental performance), and support greater inclusion in public procurement and subsidy schemes.

The inclusion of BBIM in public and private construction projects also depends on the availability of verified environmental data, such as LCAs and EPDs. To address this, the "Witte Vlekken" (White Spots) programme by the NMD offers partial reimbursement for manufacturers developing missing LCAs, particularly for innovative or underrepresented materials (Stichting Nationale Milieudatabase, 2023). While the process is still resource-intensive, this initiative lowers the threshold for entering certified databases and increasing product visibility. Similarly, the BCRG database, which lists approved building products for the Dutch market, represents an opportunity for BBIM manufacturers to build trust and credibility. As many project tenders now require products to be listed in BCRG, inclusion can significantly enhance market access (BCRG, n.d.).

Beyond policy frameworks and certification tools, there is growing momentum in the Netherlands and across the European Union to support innovation and investment in sustainable building materials, including BBIM. This momentum is backed by financial instruments and strategic programmes that enhance the business case for manufacturers. In the Netherlands, the Green Projects Scheme (Regeling Groenprojecten) offers favourable financing conditions, such as lower interest rates, for environmentally friendly investments that meet specific innovation and sustainability criteria (RVO, 2021) . At the European level, the European Green Deal and its Circular Economy Action Plan place the construction sector among the priority areas for decarbonization and circularity, promoting sustainable product design, resource efficiency, and waste reduction (European Commission, n.d.). These EU ambitions are mirrored by the Dutch government's own target of achieving a fully circular economy by 2050, with the construction sector identified as a key area of intervention (Ministerie van Infrastructuur en Waterstaat [IenW], n.d.). Through the Circular Economy Implementation Programme, the Dutch government facilitates projects, pilots, and partnerships aimed at accelerating this transition. These strategic efforts are supported by broader industry initiatives, such as the World Green Building Council's EU roadmap for climate-neutral construction, which encourages national governments to invest in low-carbon building materials and renovation practices (WGBC, 2022). Together, these frameworks create an increasingly supportive environment for BBIM manufacturers, encouraging innovation, facilitating investment, and reinforcing the long-term relevance of sustainable material production in the Dutch renovation sector.

Other European countries have also introduced incentives that could serve as inspiration for the Dutch context. In France, carbon performance regulations such as RE2020 set strict limits on the embodied emissions of building materials, effectively favouring low-carbon products like BBIM (BCG, 2024). In Sweden, tax deductions and grants help reduce the cost gap between conventional and bio-based materials, making sustainable options more attractive to both manufacturers and builders (Le et al., 2025). Drawing on international examples like these could support Dutch manufacturers and policymakers in accelerating the market uptake of BBIM in renovation projects.

This growing alignment between national policy goals, financial incentives, and industry initiatives marks an important shift for manufacturers of BBIM. While challenges persist, the broader regulatory and investment environment is increasingly oriented toward materials that support CO_2 reduction, circularity, and local sourcing. As this policy landscape continues to evolve, manufacturers are not only better positioned to scale up production but also to take a leading role in shaping the future of sustainable renovation in the Netherlands.

3.2.6 Conclusion

This section has explored the key barriers and drivers shaping the adoption of BBIM in Dutch housing renovation, with a specific focus on manufacturers. It shows that the biggest hurdles regarding Cost contain higher material prices, investment challenges and lack of sufficiently attractive subsidies, or knowledge thereof. The Quality of BBIM also has its challenges, such as lower performance compared to CIM, inconsistency and increasing demand for certificates and declarations. Lastly, barriers pertaining to Knowledge include a lack of awareness, transparency and expertise. At the same time, new opportunities emerge through evolving regulations, financial incentives, and increasing interest in sustainable construction. Manufacturers occupy a crucial position in this landscape, as they currently create a bottleneck. Where raw BBM are produced sufficiently, and demand is growing, manufacturing is lagging behind. While the barriers identified here reflect broader systemic dynamics within the construction industry, many of these challenges become particularly tangible at the level of manufacturing. The following chapter builds on this analysis by turning to the literature on systemic innovation, offering a framework for understanding how structural change in the sector supports a wider shift toward BBIM adoption.

3.3 Systemic Innovation

The construction industry is widely regarded as one of the most difficult sectors to innovate. Fragmented supply chains, risk-averse procurement practices, and strict regulatory environments often reinforce the use of familiar methods and materials. As explored in the previous chapter, BBIM remain underutilised in the Dutch renovation sector, despite their environmental benefits and growing policy support. This points to a deeper issue: innovation in the AEC industry cannot be understood as a matter of product choice alone, but rather as a systemic challenge. Manufacturers, who play a central role in translating raw materials into market-ready products, are especially affected by this lack of systemic flexibility.

This chapter explores how innovation in the AEC sector can be understood and supported from a systemic perspective. Systemic innovation refers to changes in construction systems that make space for new technologies, practices, and relationships (Hall, Whyte & Lessing, 2019). To better understand how such change can take place, this chapter draws on three key bodies of literature: the concept of the mirroring trap, Rogers' theory on the diffusion of innovations, and strategic niche management. Together, these perspectives help frame the structural and cultural barriers that limit innovation, and offer insight into how BBIM adoption might be accelerated through coordinated change.

The chapter begins with a brief overview of the mirroring trap, which helps explain how organisational structures tend to reproduce existing practices. It then discusses diffusion theory and how it applies to construction innovation Finally, the chapter explores how innovation can be supported and protected through Strategic Niche Management. These frameworks provide the conceptual foundation for analysing the challenges faced by BBIM manufacturers and the conditions under which systemic change might occur, contributing to the central aim of this study: understanding how the use of BBIM can be stimulated in Dutch housing renovation.

3.3.1 Mirroring trap

The limited uptake of BBIM in the construction sector is not only a matter of innovation characteristics or individual decisions, but is also closely linked to how the industry is structured. One concept that helps explain this structural resistance to change is the "mirroring trap," as introduced by Hall (2018). The mirroring trap refers to the tendency of organisations and technologies to reflect the fragmented and decentralised structures of the systems in which they operate (Hall, Whyte & Lessing, 2019). In the construction industry, where responsibilities are often divided among many loosely connected actors and projects are organised on a temporary, one-off basis, innovation struggles to gain momentum (Hall, 2018).

In this context, the physical and organisational fragmentation of construction leads to repeated replication of familiar practices. Each new project starts with a clean slate, involving a new team of contractors, suppliers, and consultants, all of whom often revert to what they know works. This decentralised, project-based model makes it difficult for system-wide learning or cumulative innovation to occur. Instead of building on previous experiences, projects tend to "mirror" the current industry norms and structures, reinforcing path dependency and slowing the uptake of new materials such as BBIM.

For manufacturers, this mirroring effect can be particularly constraining. Even when a manufacturer is willing to innovate, the limited influence they have over specification, procurement, and project planning means that their BBIM products may not be selected. Architects and contractors often specify materials based on what is familiar, widely available, and proven in similar projects. Manufacturers looking to introduce BBIM must therefore overcome not only technical and economic barriers, but also the inertia embedded in the routines and expectations of other stakeholders.

Hall, Whyte and Lessing (2018; 2019) suggest that breaking the mirroring trap requires some level of integration within the construction process. Full vertical integration, where design, manufacturing, and construction are handled by a single entity, is one solution, but less extreme forms of collaboration can also be effective. For example, long-term partnerships between manufacturers and housing associations or design-build teams can help align incentives and reduce fragmentation (Chao-Duivis. Koning & Ubbink, 2013; Hall, 2018). These forms of collaboration enable early engagement, better coordination, and more openness to specifying innovative materials like BBIM.

The concept of the mirroring trap highlights how deeply ingrained fragmentation in the construction industry hinders the uptake of innovative materials like BBIM. This structural inertia means that even when BBIM manufacturers innovate, their products often face resistance due to entrenched procurement practices and project-based fragmentation. For the Netherlands, where housing renovation is a pathway to achieving sustainability goals, addressing this mirroring effect is vital. Encouraging more integrated project delivery methods, such as design-build contracts or long-term partnerships with housing associations, can disrupt traditional patterns and create room for BBIM adoption. These collaborative approaches enable early-stage specification of BBIM, streamline communication, and reduce project-based islands, thus providing a pathway to scale up BBIM use in renovation projects. Tackling the mirroring trap is, therefore, not just a structural adjustment, but a strategic step toward sustainable housing renovation in the Dutch context. Which factors can be further influenced to facilitate innovation, is explored in the following section about diffusion of innovations.

3.3.2 Diffusion of Innovations

Diffusion of innovations, as defined by Rogers (2003), provides a useful framework for understanding how new technologies spread within an industry, or where they fail. In the context of BBIM, this framework helps identify where manufacturers encounter hesitation, what factors shape their decision-making, and how broader industry structures may support or hinder innovation. BBIM are still relatively novel in the Dutch renovation market, and while some manufacturers have adopted them, many others remain hesitant or unconvinced. Rogers' theory offers several concepts that help explain this dynamic, including how innovations are evaluated, how decisions are made, and how social systems shape the pace of change.

Rogers outlines five key characteristics that influence the rate of adoption of an innovation (Figure 8): relative advantage, compatibility, complexity, trialability, and observability (Rogers, 2003). When applied to BBIM, each of these factors can act as either a driver or a barrier for manufacturers. While BBIM clearly offer a relative advantage in terms of sustainability and carbon storage, this may not directly translate into perceived business advantage if it does not align with financial or operational goals. Compatibility also presents a challenge: BBIM often require different production processes or supply chains, making them harder to integrate into existing systems. Complexity is another factor; due to limited experience with these materials, manufacturers may perceive BBIM as more difficult to produce, test, or certify. Trialability and observability also play significant roles. If manufacturers cannot easily test BBIM on a small scale, or if successful projects are not visible within their networks, the perceived risk of adoption remains high.

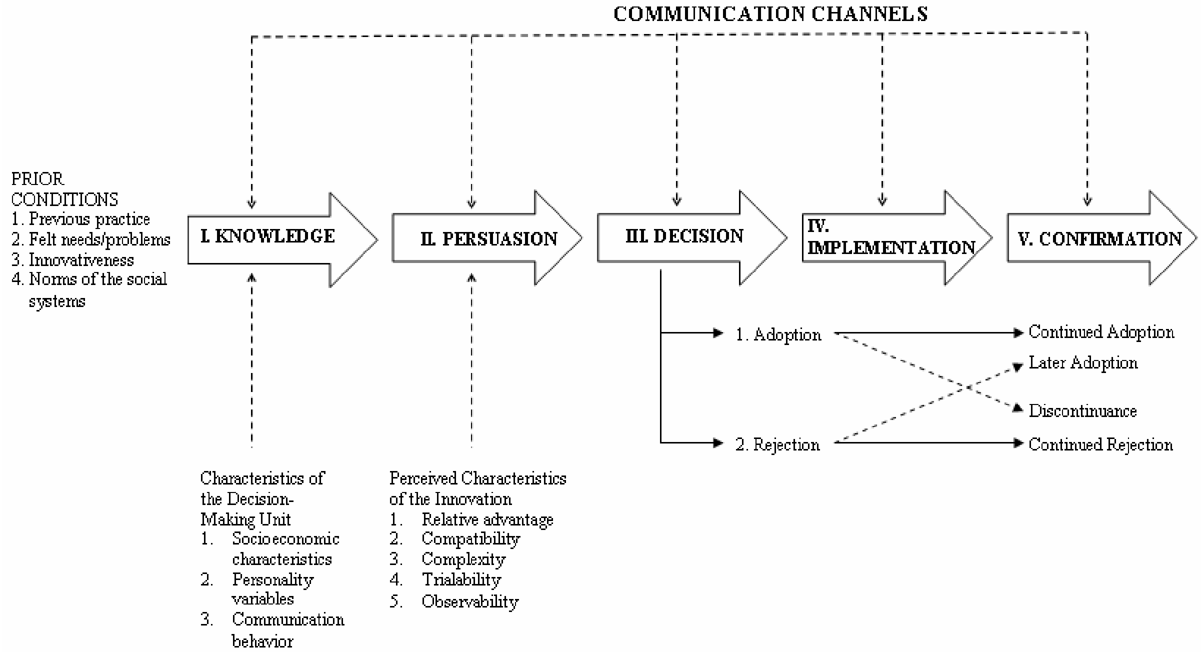

Figure 8 – Model of Five Stages in the Innovation-Decision Process (Rogers, 2003, p. 170)

These five innovation attributes map closely onto the five stages of the innovation-decision process (Figure 8): knowledge, persuasion, decision, implementation, and confirmation (Rogers, 2003). Each stage offers insight into potential bottlenecks for BBIM adoption. In the *(I) knowledge stage*, manufacturers must become aware of BBIM and understand their function, benefits, and technical requirements (Rogers, 2003). A lack of reliable, accessible information can block progress at this early stage. During the *(II) persuasion phase*, manufacturers form a positive or negative attitude toward the innovation. This stage is highly influenced by peer opinions and perceived alignment with business goals (Rogers, 2003). If few peers are using BBIM, or if information is conflicting, a negative perception may form. This dynamic aligns with the logic of the mirroring trap, where decentralised, project-based structures in construction reinforce the replication of conventional practices (Hall, 2018). The *(III) decision stage* involves a clear commitment to adopt or reject the innovation (Rogers, 2003). Manufacturers may hesitate here due to uncertainty, high investment risk, or the absence of clear market demand. Trial projects or peer demonstrations can help reduce perceived risk and encourage adoption. *(IV) Implementation*, the next stage, requires translating intention into action (Rogers, 2003). At this point, manufacturers must address practical challenges such as sourcing raw materials, adjusting production processes, and navigating certification pathways. Finally, *(V) confirmation* refers to post-adoption reinforcement; if results are positive, the innovation becomes integrated. If challenges arise or benefits are unclear, the innovation may be abandoned (Rogers, 2003).

Rogers (2003) also highlights that preventive innovations (those adopted to avoid future negative outcomes rather than secure immediate benefits) are particularly difficult to promote. In the case of BBIM, the primary benefits often relate to long-term climate goals and health impacts, which may not feel urgent or financially compelling to manufacturers. This reinforces the need for positive incentives and strong peer examples.

To address these challenges, Mlecnik (2013) introduces the idea of learning cycles and innovation networks. Rather than moving through the innovation-decision process in isolation, stakeholders can engage in shared learning environments. These networks allow manufacturers to exchange knowledge, test ideas collaboratively, and maintain motivation through peer support (Mlecnik, 2013).

The diffusion of innovations framework underscores the multifaceted challenges that BBIM face in gaining traction within the Dutch renovation market. While these materials offer clear environmental benefits, their adoption is often hindered by issues related to compatibility with existing practices, perceived complexity, and limited trialability. Rogers' model illustrates how each phase of the innovation-decision process represents a potential bottleneck for BBIM adoption, particularly in the knowledge and persuasion stages where lack of awareness and peer influence can stall progress. For BBIM to move beyond these barriers, targeted strategies such as peer-driven demonstrations, collaborative learning environments, and visible pilot projects are essential. These approaches not only reduce perceived risk but also build trust and familiarity among manufacturers. Integrating BBIM into visible, successful renovation projects would help to overcome hesitation and stimulate wider acceptance, paving the way for these sustainable materials to become mainstream in the Dutch construction industry. This sets the stage for the next section, which explores how strategic niche management can help create the protected spaces and collaborative networks needed to support systemic innovation.

3.3.3 Strategic Niche Management

Strategic Niche Management (SNM) is a framework for understanding how innovations can be supported and guided in the early phases of development, especially when they face resistance from dominant regimes, as is the case with the mirroring trap. SNM emphasises the creation of "niches," or protected spaces, where new technologies and practices can be tested, developed, and refined without the immediate pressures of the mainstream market (Kemp, Schot & Hoogma, 1998). These niches provide room for experimentation, allowing actors to learn, build networks, and co-develop visions that guide the innovation process.

In the context of BBIM, SNM helps explain how systemic innovation might be supported within a traditionally conservative construction industry. Given the high risk and uncertainty associated with BBIM production, manufacturers benefit from spaces where they can experiment with new materials, techniques, and partnerships. However, the effectiveness of such niches depends on three interrelated processes: vision development, learning, and networking (Schot & Geels, 2008).

Vision development refers to the formulation of shared expectations and goals that provide direction for niche actors (Schot & Geels, 2008). In the case of BBIM, this could include visions of carbon-neutral construction, circular material flows, or localised bio-based supply chains. A strong and coherent vision can help align the interests of different actors, reduce uncertainty, and attract investment. It also enables manufacturers to articulate the broader value of BBIM beyond short-term financial gains.

Second-order learning is another core element of SNM. Unlike first-order learning, which focuses on technical performance or incremental improvements, second-order learning involves questioning underlying assumptions, practices, and frameworks (Hoogma, Kemp, Schot & Truffer, 2002). For BBIM manufacturers, this might include rethinking quality norms, exploring new business models, or redefining success metrics to include environmental and social outcomes. Such learning processes enhance the adaptive capacity of niche actors and support long-term innovation.

Networking is essential for embedding innovations within a broader support structure. In SNM, networks are not only about sharing knowledge but also about mobilising resources, gaining legitimacy, and creating mutual dependencies (Schot & Geels, 2008). For BBIM manufacturers, building strong relationships with architects, developers, local governments, and research institutions can help generate demand, improve technical understanding, and influence policy. These networks also support collective learning and help sustain momentum when initial enthusiasm fades.

Together, these processes help stabilise and strengthen innovation niches. For BBIM, this means moving from isolated pilot projects to integrated, multi-actor collaborations that align with broader sustainability goals. However, creating and maintaining such niches requires intentional coordination and long-term support, particularly in sectors like construction, where systemic inertia and fragmented practices remain strong. SNM therefore offers a valuable framework for understanding how manufacturers, policymakers, and other stakeholders can work together to foster the conditions needed for BBIM to succeed. The continued relevance of SNM is further underscored by recent work such as Giganti and Falcone (2022), who demonstrate the framework's enduring value across various sustainability transitions, especially in the Netherlands. In the context of this thesis, SNM offers a valuable lens for identifying how BBIM manufacturers in the Netherlands might overcome structural barriers and co-create enabling conditions for systemic change.

3.3.4 Conclusion

This section has introduced three complementary frameworks that provide strategic insights into how innovation in the construction sector can be actively supported. The concept of the mirroring trap highlights the deep-seated structural barriers within the construction industry's fragmented and project-based approach. Overcoming this requires more integrated, collaborative project delivery models that enable BBIM to break through established routines and be consistently specified in renovation projects. Rogers' Diffusion of Innovations theory further explains the pathways through which BBIM can gain traction, emphasizing the need for visible success stories, reduced complexity through knowledge sharing, and stronger peer-driven trust. For BBIM, this means that manufacturers not only need to innovate their production processes but also build trust across the construction value chain. Finally, SNM provides a roadmap for stabilising these innovations through the creation of protected environments, enabling multi-actor collaborations that can nurture BBIM from niche applications to mainstream solutions.

Though distinct in their focus, the three frameworks collectively underscore the need for learning, peer influence, and coordinated action. For BBIM to scale effectively in Dutch housing renovation, manufacturers must engage with policymakers, architects, and contractors in long-term partnerships, leveraging shared learning and co-created projects. These frameworks suggest that scaling up BBIM is not solely a matter of technological readiness but requires systemic shifts in collaboration, trust-building, and market integration. Successfully implementing these strategies could bridge the gap between pilot projects and widespread application, ultimately helping BBIM become a viable and sustainable option for Dutch housing renovation.

3.4 Literature Conclusion

This literature study provides a comprehensive understanding of the current status, challenges, and opportunities for BBIM in the Dutch housing renovation sector. The exploration of BBIM forms a large basis for answering sub-question 1, about which materials can be used for insulation in renovation projects. It reveals that batts made out of flax, hemp, reed and straw stand out as viable options for sustainable insulation. While these materials generally require more thickness compared to CIM, their benefits in moisture regulation and environmental sustainability make them promising alternatives. Furthermore, batts made from miscanthus and straw-based blow-in insulation present particularly effective solutions for quick and cost-efficient application, provided that technical expertise is available for the implementation of blow-in insulation.

The investigation into barriers and drivers answers a part of sub-question 2, about overcoming these barriers or deploying found drivers effectively to increase BBIM production. It shows critical challenges impacting the adoption of BBIM in the Dutch housing sector. Cost remains a significant barrier, driven by higher material prices, investment challenges, and a lack of sufficiently attractive subsidies. In terms of quality assurance, BBIM often underperform compared to CIM, with concerns over inconsistency and increasing demands for certifications and environmental declarations. Knowledge gaps are also evident, particularly in awareness, transparency, and expertise regarding BBIM properties and applications. These barriers are compounded at the manufacturing stage, where production lags behind both raw BBM availability and growing market demand, creating a bottleneck that stifles widespread adoption. Despite these hurdles, evolving regulations, financial incentives, and a rising interest in sustainable construction present clear opportunities for market expansion.

To lay a foundation for answering sub-question 3, by understanding how BBIM manufacturing can be effectively scaled up, the literature also explored concepts from systemic innovation, including the mirroring trap, Rogers' Diffusion of Innovations, and SNM. These theories emphasize that sustainable adoption requires not only technical improvements but also structural changes within the construction sector. Strategies like increasing the visibility of successful projects, restructuring market practices, and establishing collaborative learning environments can mitigate industry inertia.

Together, these insights lay the groundwork for the next phase of research, which involves qualitative analysis through exploratory and semi-structured interviews with key stakeholders. These interviews aim to validate the literature findings and provide a deeper understanding of how the identified barriers and drivers are experienced in practice. Furthermore, they will explore the practical feasibility of innovation-driven strategies to support the upscaling of BBIM in renovation projects across the Netherlands.

4 Qualitative Research

This section presents the qualitative research conducted to explore the factors influencing the production of BBIM. It begins with an overview of the exploratory interviews, which serve as a preliminary investigation to refine the research focus and develop relevant interview questions. The next part details the semi-structured interviews, explaining the selection of participants, the formulation of questions, and any adjustments made during the process. Following this, the key findings from the interviews are presented, highlighting recurring themes, barriers, and drivers identified by manufacturers. Finally, the section concludes with a preliminary analysis of the results, laying the groundwork for answering the main research question and informing the discussion and conclusion of this study.

4.1 Exploratory Interviews

The exploratory interviews were designed to identify key challenges and opportunities in scaling up BBIM by engaging directly with manufacturers who have successfully implemented bio-based insulation production. To develop the interview focus, insights from the literature review and the overarching research goals were taken into account, ensuring that discussions address critical industry barriers, market dynamics, and enabling factors. The questions evolved during the interview process, allowing for flexibility in exploring unexpected yet relevant themes (Appendix B). Five interviewees were selected through two primary methods: contacting The Green Village and identifying manufacturers via distribution websites. The Green Village, a field lab for sustainable innovation at TU Delft, served as a testing ground for new technologies in the built environment. Its focus on circular construction and sustainable materials makes it a valuable resource for connecting with industry professionals already engaged with bio-based insulation. The selection process prioritized companies that exclusively manufacture BBIM, providing a foundational understanding of the barriers they have successfully navigated and the strategies employed to overcome them. Additionally, email contact was established with a company that has discontinued the production of BBIM. Although not interviewed directly, their response offered a concise summary of the key reasons for exiting the market: limited technical capacity, difficulty complying with European certification standards, and insufficient thermal performance of their product compared to fossil-based alternatives. This case illustrates that even companies with sustainability ambitions may be deterred by a combination of technical, regulatory, and market-based barriers, reinforcing several of the challenges that later emerged in interviews. This approach helps establish a basis for analysing why other manufacturers remain hesitant to enter the BBIM market and whether their concerns are well-founded.

In addition to manufacturers, five interviews were conducted with professionals from the renovation sector, offering valuable insights into the practical challenges faced when adopting BBIM in renovation projects. One contractor emphasized the importance of choosing insulation materials that balance performance with ease of installation. They noted that, while using BBIM offers significant environmental benefits, there are still challenges to its widespread adoption, particularly in cases where time or cost constraints prevent waiting for regulatory approval of certain building assemblies. For instance, while some bio-based constructions are not yet fire-tested or fully certified according to local standards, others, which have already received approval, could be used as a reliable reference in similar projects. In such cases, consultants might be called in to substantiate that a specific assembly would meet regulatory requirements, without having to test again. This underscores the complexities that professionals in the field face when navigating the regulatory environment.

Moreover, when it comes to the choice of materials, cost considerations play a significant role, with the installation of BBIM sometimes being perceived as more expensive. The installation process itself is a key factor in decision-making, as contractors often prefer materials that are easier to implement, thus reducing labour costs. Prefabricated materials combined with bio-based insulation, such as blown-in options, show promise but require a shift in working practices, which can be met with some resistance. The contractor's experience highlights how adopting new materials can bring both opportunities and challenges, as they play an increasingly pivotal role in driving innovation in construction. Furthermore, certification remains an important driver, with fire safety and environmental credentials being critical factors in selecting materials, even as international certification schemes pose barriers when products are registered outside of the Netherlands.

The interviews revealed several recurring challenges. Price remains a major barrier, as BBIM is often more expensive than conventional alternatives, making marketing and customer education crucial, yet challenging, particularly for smaller companies. Certification requirements, such as LCAs and EPDs, are necessary for accessing subsidies but are costly and time-consuming. Additionally, new BBIM often face stricter scrutiny than conventional insulation products. Regulatory differences and language barriers further complicate international expansion, particularly when registering products in foreign databases. Technical challenges include fire safety concerns, lower thermal performance requiring thicker materials, and the need for specialized manufacturing and installation knowledge. However, the findings also highlight opportunities: sustainability policies are driving demand, timber construction is gaining traction, and advancements in recycling create new possibilities for material innovation.

Building on these insights, the next phase of research involves semi-structured interviews with a broader range of manufacturers, including those who have or have not (yet) adopted BBIM. These interviews will further explore the key barriers and opportunities identified in the exploratory phase, such as cost, certification challenges, and technical constraints, while also examining the motivations, concerns, and external factors that influence manufacturers' decision-making. This approach provides a more comprehensive understanding of the barriers and drivers shaping the industry and informs potential policy interventions to support BBIM adoption. These exploratory interviews were not included in the formal coding process, as they served primarily to inform the design and thematic scope of the subsequent semi-structured interviews rather than to generate systematically comparable data.

4.2 Semi-structured Interviews

For the semi-structured interviews, four different categories of insulation manufacturers are identified. The first includes companies founded specifically to produce BBIM (founders). The second consists of companies that originally produced CIM but have since adopted or expanded into BBIM production (adopters). The third category comprises companies that exclusively produce CIM and have not yet adopted BBIM (hold-outs), while the fourth represents companies that reject BBIM entirely and do not consider its production (rejectors). In practice, however, companies that completely reject BBIM are very difficult to identify. Most manufacturers have at least explored the possibility of producing BBM, and even those who have chosen not to pursue it tend to remain open to the idea. As a result, no companies in this category are included in the interviews.

A total of six insulation manufacturers participated in the semi-structured interviews, with partial overlap with the exploratory interviewees. These were conducted online and lasted between 51 and 82 minutes, depending on availability. Participants represented both small and large companies, with small companies defined as those employing fewer than 100 people. The distribution of interviewees across company types is shown in Table 3.

Respondents	**Function**	**Company size**	**Company Category**	**Interview Length**	**Interview Date**
1	Specialist	Large	Hold-out	01:18 hrs	07/03/2025
2	Manager	Small	Founder	01:22 hrs	11/03/2025
3	Manager	Large	Adopter	01:03 hrs	07/04/2025
4	Founder	Small	Founder	01:19 hrs	07/04/2025
5	Specialist	Small	Founder	00:51 hrs	01/04/2025
6	Manager	Large	Hold-out	01:22 hrs	11/03/2025

Table 3 – Demographics of interviewees (own work)

Due to the diversity among the companies, the barriers and drivers they experience are not necessarily comparable. Therefore, three separate sets of interview questions were developed: one each for the founder, adopter, and hold-out categories. These questions were primarily based on the Literature Study and were further refined using insights gained from the exploratory interviews. This approach allowed for tailored discussions that reflect the unique context of each company type, while still addressing common categories such as Cost, Quality Assurance and Knowledge. The full question guides are provided in Appendix C – Interview Questions.

A large number of manufacturers were contacted to recruit participants for this phase. In several cases, companies either did not meet the selection criteria, for example, by producing non-plant-based materials or products unsuitable for the Dutch renovation context, or they did not have time to participate. Some interviewees from the exploratory phase also did not take part in this round of interviews. While their absence limits continuity across phases, their earlier contributions helped inform the direction of the semi-structured interviews. Although the sample size is relatively small, the interviews reflect a wide range of perspectives from companies of different sizes and at various stages of BBIM adoption.

4.3 Results

The interview guides were initially structured around four thematic categories: cost, quality assurance, knowledge, and drivers. However, during the coding and analysis phase, it became clear that "drivers" was better understood as a dimension within each category (i.e., each category includes both barriers and drivers), and a new category, "policy", was introduced to capture recurring insights related to regulation and government support (Figure 9). This adapted framework allowed for a more nuanced and policy-relevant understanding of the findings. Figure 10 shows an overview of the occurrence across interviews of each category as barriers and/or drivers.

Figure 9 – Expanded Innovation Barriers in the AEC industry (own work)

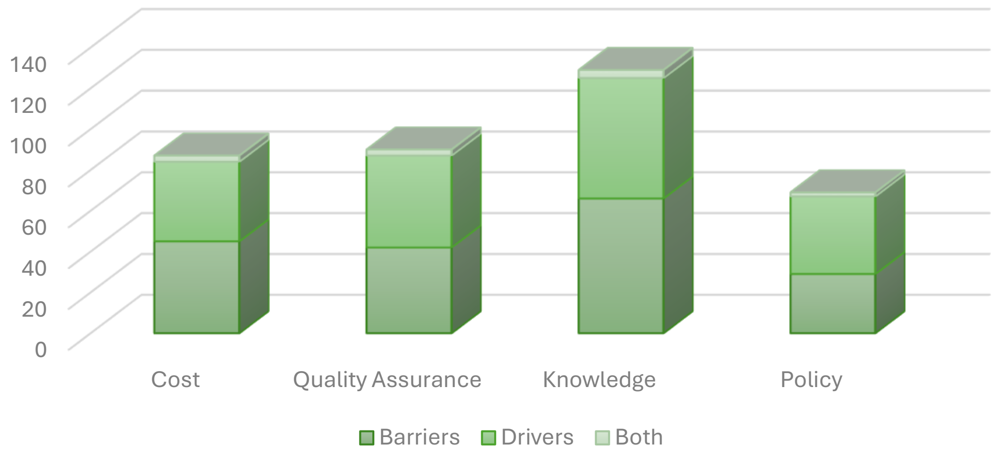

Figure 10 - Co-occurence of quotation codes in ATLAS.ti (own work, based on Appendix Table 1)

The Figure shows that participants spoke in relatively equal frequency about barriers and drivers, with some statements classified as both. This occurred when interviewees described interventions or factors that had both advantages and disadvantages, depending on the context. For instance, government regulations were sometimes seen as a driver for encouraging sustainability, but also as a barrier when compliance costs were high.

Interestingly, even though participants often identified cost and policy as the most critical barriers and drivers during the interviews, Figure 10 indicates that knowledge was the most frequently discussed category. This suggests that, while cost and regulatory barriers may be perceived as crucial, knowledge gaps represent a broader and more pervasive challenge for the sector. This could indicate that participants feel more confident addressing financial and policy barriers, but recognize uncertainties or deficiencies in technical understanding as a major issue.

An additional layer of analysis reveals that the experiences of large and small companies differ significantly across the four main categories: Cost, Quality Assurance, Knowledge, and Policy. Small companies, which are predominantly founders of BBIM production, tend to experience Cost as a significant barrier, while large companies, primarily hold-outs or adopters, view cost more often as a driver for scaling and market expansion (Appendix Figure 1). This contrast extends to Quality Assurance, where smaller firms report an almost equal distribution of barriers and drivers, while larger firms still report more barriers than drivers but with a smaller gap (Appendix Figure 2). In the case of Knowledge, small companies surprisingly perceive more drivers than barriers, whereas larger firms encounter more barriers (**Error! Reference source not found.**), reflecting differences in technical expertise and market access. Finally, in the category of Policy, the difference is less pronounced, with both company sizes expressing similar challenges and opportunities (Appendix Figure 4). These distinctions suggest that company size not only influences the perception of barriers and drivers but may also affect strategic decision-making in the adoption of BBIM.

The following text explains the most important barriers and drivers per category: Cost, Quality Assurance, Knowledge, and Policy. This analysis operates on the assumption that thematic importance correlates with the frequency of discussion. The more often a topic is raised by participants, the more critical it is perceived to be for the sector. This does not exclude the importance of less-discussed barriers and drivers but highlights the most commonly recognized challenges and opportunities. Additionally, there is considerable overlap between the subcategories, as factors such as cost and regulation, for example, often influence aspects of quality assurance and knowledge. This interconnectedness reflects the complexity of upscaling BBIM production, where barriers and drivers are rarely isolated.

4.3.1 Cost

Cost emerged as a critical theme during the analysis of barriers and drivers for the upscaling of BBIM production. Financial considerations were frequently cited by interviewees as a primary determinant of feasibility and competitiveness. The category of Cost is structured into four subcategories: Certification Costs, Investment Costs, Operational Costs, and Production Costs. These costs are interconnected, with investment decisions impacting production efficiency, and certification costs influencing market accessibility. According to the co-occurrence analysis (Figure 11), Investment Costs were identified as the most impactful barrier, followed by Production Costs, Operational Costs, and finally Certification Costs. While barriers dominate the discussion, several potential drivers were also identified, particularly for larger companies that are better positioned to leverage economies of scale and optimize supply chains. The following sections provide a detailed examination of each cost subcategory, outlining both the challenges and opportunities they present.

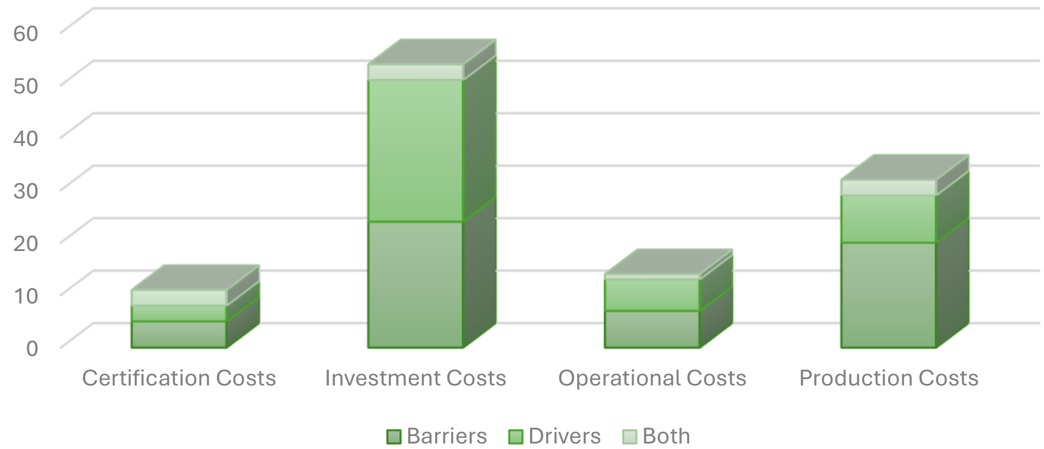

Figure 11 – Co-occurrence of "Cost" quotations in ATLAS.ti (own work, based on Appendix Table 2)

Smaller manufacturers may struggle with Certification Costs. Interviewees mainly emphasized the high costs of third-party certifications, such as EPDs and LCAs, which are necessary for market access and public tenders. These costs include testing, documentation, and compliance procedures, which are often repeated for different markets due to international regulatory discrepancies. One respondent highlighted the difficulty in meeting both European and local standards, noting that certification processes are lengthy and expensive, especially when re-certification is required across borders. While larger companies can generally absorb these costs, smaller manufacturers experience financial strain, limiting their capacity to scale. Despite these challenges, certification remains a critical driver for gaining credibility, access to public tenders, and entrance into international markets, which can significantly enhance growth opportunities for companies that achieve compliance.

Investment Costs are identified as the most significant barrier to the upscaling of BBIM, especially when compared to other cost categories. The high initial capital expenditure required for technology acquisition, infrastructure upgrades, and production line development poses a substantial challenge. Respondents frequently mentioned the difficulty of obtaining funding for scaling up operations and investing in specialized machinery. Additionally, long-term contracts with suppliers are often necessary to secure consistent material flow, representing another layer of financial commitment. One interviewee noted that investment costs are particularly daunting for small manufacturers, as they often lack the financial reserves needed for long-term contracts with supply partners or for implementing new technologies. These costs are further exacerbated by the need for certified facilities that comply with regulatory standards, driving up initial expenses. Larger companies, however, often view these investments as strategic drivers that enable market dominance and scalability. If secured successfully, these investments allow for increased production capacity, improved market positioning, and stronger competitiveness in both domestic and international markets.

Since Operational and Production Costs show great overlap, the two sub-categories are merged in this section. These costs encompass the Total Cost of Ownership, so the day-to-day expenses of running production lines as well as the transformation of raw materials into finished products. Interviewees frequently emphasized the high energy demands, labour intensity, and specialized equipment required for BBIM production. Sustainable raw materials often command higher prices than conventional alternatives, making it challenging for smaller manufacturers to compete with larger firms that benefit from bulk purchasing agreements and optimized supply chains. Additionally, fluctuating energy prices and the need for sustainable supply chains introduce vulnerabilities, particularly for smaller companies. Achieving economies of scale is a recurring obstacle, as scaling up production does not always result in proportional cost reductions due to the complexity of manufacturing processes. Despite these barriers, improvements in energy efficiency, process automation, and technological advancements are seen as potential drivers for reducing costs. For larger manufacturers, strategic investments in technology and infrastructure allow for greater resilience and cost-effectiveness, positioning them competitively in the market.

The analysis of Cost reveals that financial barriers significantly influence the adoption and scalability of BBIM production. Investment Costs stand out as the largest obstacle, primarily due to the high capital requirements for technology and infrastructure development. Production Costs and Operational Costs also pose challenges, especially for smaller companies that struggle to achieve economies of scale. Furthermore, Certification Costs create additional hurdles, particularly when international regulatory discrepancies require multiple rounds of testing and approval. Despite these challenges, the analysis also highlights clear drivers for growth. For larger companies, strategic investments, bulk purchasing, and optimized energy use enable competitive positioning and market expansion. Improved technological efficiency and the streamlining of certification processes could further lower cost barriers, paving the way for broader adoption of BBIM. Addressing these financial constraints is crucial for unlocking the potential of sustainable insulation materials in the construction sector.

4.3.2 Quality Assurance

Quality assurance is a crucial factor for the market acceptance and scalability of BBIM. Within this category, two main subcategories were identified: Certifications and Performance and Reliability, of which Performance and Reliability emerged as the dominant concern (Figure 12). This suggests that while certifications are necessary for regulatory compliance and market entry, the real challenge lies in proving the effectiveness and durability of BBIM compared to CIM. Manufacturers emphasized the importance of thermal performance, fire safety, and long-term reliability as critical factors influencing market acceptance. These concerns are particularly pronounced for smaller manufacturers, who often lack the resources to perform extensive testing and certification. The following sections detail the barriers and drivers within these two subcategories, demonstrating how quality assurance both restricts and enables the scaling of BBIM in the construction sector.

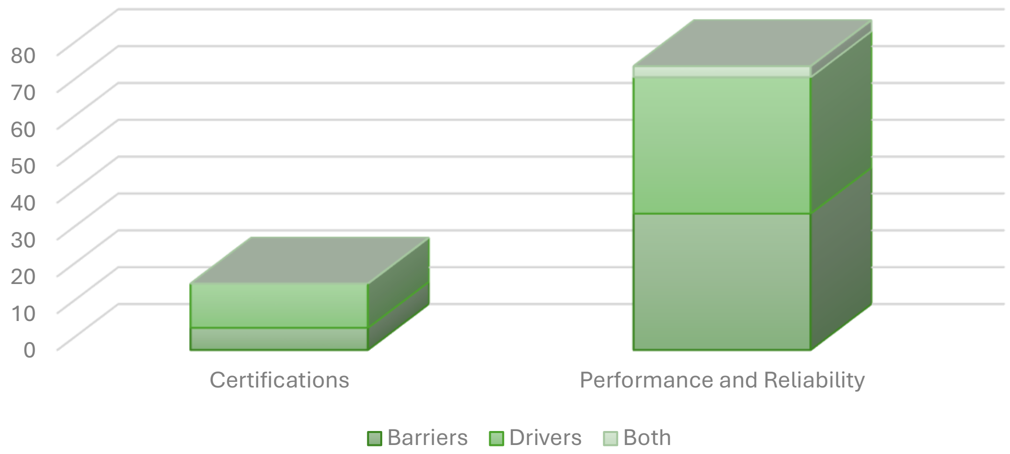

Figure 12 – Co-occurrence of "Quality Assurance" quotations in ATLAS.ti (own work, based on Appendix Table 3)

Obtaining Certifications such as EPDs and LCAs is often a significant hurdle for BBIM manufacturers. Interviewees emphasized that the process is both costly and time-consuming, especially for smaller companies. One respondent noted that EPDs expire every five years, necessitating regular renewals that further drive up costs. International market entry frequently requires re-certification to meet varying regulatory standards, multiplying expenses and administrative burdens. Despite these barriers, certifications are also perceived as a driver for market credibility, enabling access to sustainable building projects and enhancing trust with clients. While smaller companies are often not yet certified, larger companies leverage certifications as a competitive advantage, positioning themselves as industry leaders in sustainability and compliance.

Performance and Reliability are key considerations for the adoption of BBIM in the construction sector, emerging as the most frequently mentioned theme within Quality Assurance. Interviewees emphasized that BBIM products are often scrutinized for their thermal performance, fire resistance, and long-term durability compared to CIM. Several respondents mentioned that BBIM sometimes requires thicker applications to achieve the same insulation value as traditional materials, which can be perceived as a disadvantage in space-constrained projects. Fire safety remains a critical concern as well, with manufacturers required to meet stringent fire-resistance standards to gain market acceptance. Furthermore, the lack of long-term performance data for some biobased materials raises questions about their reliability in large-scale construction projects. Despite these challenges, interviewees noted that advancements in product development and certification are gradually enhancing BBIM's performance metrics, positioning it as a more competitive alternative to CIM. Improved reliability and increasing certification rates are seen as important drivers for mainstream adoption.

The analysis of Quality Assurance reveals that Performance and Reliability is the primary challenge for BBIM manufacturers, significantly outweighing Certifications in terms of perceived barriers. Concerns about thermal efficiency, fire safety, and long-term durability represent substantial obstacles for market acceptance, particularly for smaller companies that struggle to meet these standards consistently. In contrast, certifications, though costly and administratively demanding, serve as gateways to new markets and public tenders. Larger companies are better positioned to leverage these certifications as competitive advantages, while smaller firms often remain excluded from key projects due to certification barriers. Addressing these performance concerns through technological innovation and improved testing protocols could enhance the reliability of BBIM and facilitate broader market adoption. Streamlining certification processes could further support smaller manufacturers, enabling them to participate in sustainable construction projects with greater confidence.

4.3.3 Knowledge

Knowledge emerged as the most frequently discussed category in the analysis, underlining its significance in the adoption and scaling of BBIM. This category is divided into two main subcategories: Expertise and Training and Education. Of the two, Expertise was mentioned considerably more often (Figure 13). This indicates that while structured learning is important, it is the practical and technical know-how that forms the primary barrier and driver for BBIM expansion. Expertise is critical for understanding the unique properties of BBIM, optimizing production processes, and meeting regulatory standards. Simultaneously, training initiatives are seen as vital for transferring this knowledge across the value chain, from manufacturers to contractors and end-users. The following sections detail the barriers and drivers within these subcategories, highlighting how gaps in technical understanding, market awareness, and hands-on training influence the scalability of BBIM in the Netherlands.

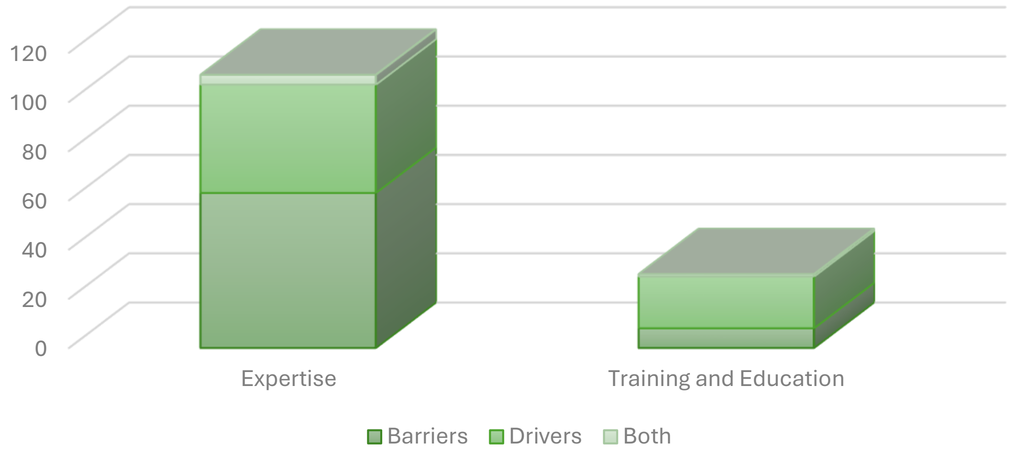

Figure 13 – Co-occurrence of "Knowledge" quotations in ATLAS.ti (own work, based on Appendix Table 4)

Expertise is the most frequently mentioned subcategory within Knowledge, reflecting its critical importance for the successful adoption and upscaling of BBIM. It encompasses a broad spectrum of required skills and insights, from technical understanding to market knowledge. Interviewees highlighted significant gaps in technical expertise, particularly concerning thermal performance, vapour permeability, and fire resistance of BBIM. Furthermore, market awareness remains low, with many industry professionals unfamiliar with the benefits and applications of biobased materials. The lack of transparent, consistent information about BBIM's characteristics leads to misconceptions, which weakens trust among end-users. This is further exacerbated by the inertia of the AEC industry, which is often reluctant to change established processes. Misunderstandings about the performance of BBIM products further contribute to market hesitation. Smaller companies sometimes struggle with scaling up, as expanding production introduces complexities that require specific expertise.

Despite these barriers, drivers for expertise are emerging. Lobbying efforts have raised awareness of BBIM's environmental benefits, contributing to its growing popularity. Larger firms have the option of acquiring BBIM manufacturers to integrate their specialized knowledge, accelerating market entry and compliance. Interviewees also noted that understanding BBIM's impact on environmental goals serves as a motivation for sustainable construction practices. Moreover, when market demand is predictable, manufacturers feel more secure in scaling up production, reducing financial risks. Finally, the growing availability of BBIM materials is expected to gradually increase technical understanding, reducing market misconceptions and building trust in their reliability.

Training and Education is not mentioned very frequently, but it greatly impacts Expertise, particularly in bridging the knowledge gap across the construction sector. Interviewees emphasized the need for targeted training programs and knowledge transfer initiatives to familiarize architects, engineers, and builders with the unique characteristics of biobased materials. One respondent highlighted the role of on-site training and practical workshops in overcoming hesitancy and building trust in BBIM's performance. Collaborative networks across the production chain, from farmers to end-users, encourage shared learning and market expansion. Campaigns aimed at increasing awareness and technical understanding have proven effective, yet they remain limited in scale. Smaller companies often lack the resources to provide structured training, further widening the knowledge gap. Additionally, misinformation and a lack of accessible information were noted as barriers, complicating efforts to educate the market. Despite these challenges, structured training and educational programs are seen as powerful drivers to overcome misconceptions and accelerate market acceptance of BBIM.

The analysis of Knowledge reveals that gaps in Expertise and Training and Education significantly influence the scalability of BBIM. The lack of technical understanding is a major barrier, particularly for smaller companies struggling with market entry. Additionally, misinformation and inconsistent data contribute to market hesitation, slowing the adoption of biobased solutions. However, increased lobbying and strategic partnerships between larger firms and BBIM manufacturers are gradually enhancing expertise within the sector. Moreover, structured training initiatives, although currently limited, are recognized as powerful tools for building market confidence and driving demand. Collaborative networks across the value chain are also emerging as drivers for shared learning and market expansion. Addressing these knowledge gaps through targeted education and transparent information sharing is crucial for accelerating BBIM adoption in the construction sector.

4.3.4 Policy

Although Policy was the least mentioned category during the interviews, its impact is deeply felt due to its role in setting legal and market standards. Two main subcategories were identified: Government Incentives and Regulatory Frameworks. While government incentives aim to lower financial barriers through subsidies and tax breaks, regulatory frameworks establish the minimum environmental and safety requirements that BBIM must meet. Regulatory Frameworks were mentioned significantly more often than Government Incentives (Figure 14), highlighting the weight of legal compliance in market operations. Many interviewees emphasized that regulatory compliance is a strict requirement, underlining that if policies were adjusted to prioritize sustainable materials, BBIM adoption would accelerate significantly. The following sections explore how both subcategories shape market opportunities and present barriers for manufacturers.

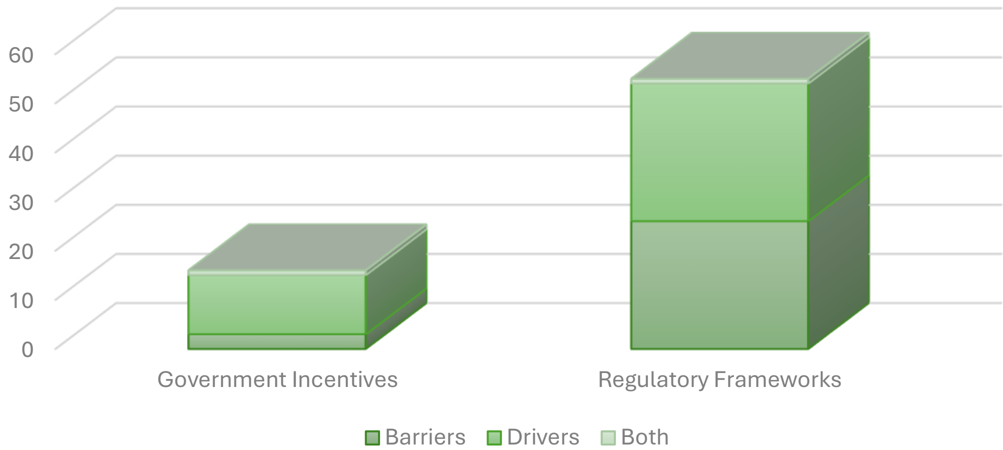

Figure 14 – Co-occurrence of "Policy" quotations in ATLAS.ti (own work, based on Appendix Table 5)

Government Incentives influence the financial landscape for BBIM production by providing subsidies, tax benefits, and financial support programs. Interviewees frequently mentioned how these incentives help offset the costs of scaling up production, enabling smaller companies to remain competitive. Some respondents highlighted the positive impact of government grants in Belgium and France, noting that similar initiatives in the Netherlands could accelerate market growth. However, awareness of these incentives is not always widespread, particularly among smaller manufacturers who may lack the resources to navigate bureaucratic procedures. Moreover, participants expressed concerns about the complexity of application processes, which often require specialized knowledge to complete successfully. On top of this, unforeseen delays during subsidy applications lead to higher costs and penalties, potentially causing bankruptcy. Despite these barriers, government incentives are seen as crucial drivers for market entry and expansion, providing financial relief and enhancing competitiveness.

Regulatory Frameworks form a critical backbone for BBIM adoption, shaping the legal requirements that manufacturers must comply with. Interviewees frequently emphasized that government regulations, such as the MilieuPresetatie Gebouwen (MPG) calculation in the Netherlands, dictate minimum environmental performance standards for construction projects. Compliance with these regulations is often described as a strict requirement, meaning that manufacturers have no choice but to meet these standards to operate legally. This rigidity can pose barriers for smaller companies that struggle to achieve certification due to high costs and administrative complexity. Additionally, international discrepancies in building codes and sustainability metrics create challenges for BBIM manufacturers looking to scale across borders. Despite these obstacles, respondents acknowledged that regulatory changes represent one of the most powerful drivers for market expansion. If stricter sustainability requirements were enforced, BBIM would become a more competitive choice, driving wider adoption through mandatory compliance.

The analysis of Policy reveals that government interventions are instrumental in shaping the landscape for BBIM production and adoption. Government Incentives were noted for their ability to alleviate financial burdens, although awareness and accessibility remain limited for smaller manufacturers. In contrast, Regulatory Frameworks act as both barriers and drivers, enforcing minimum sustainability standards that smaller companies sometimes struggle to meet. However, many interviewees expressed optimism that stricter environmental regulations could drive the broader adoption of BBIM by making compliance with sustainable standards mandatory. Streamlining certification processes and enhancing cross-border regulatory alignment could further support the scalability of BBIM. Overall, policy adjustments towards sustainability would not only benefit existing manufacturers but could also open the market to new entrants willing to invest in green innovation.

4.4 Conclusion

The qualitative analysis conducted through exploratory interviews and semi-structured interviews revealed critical insights into the barriers and drivers influencing the adoption and upscaling of BBIM in the Netherlands.

4.4.1 BBIM for Renovation

Figure 2 shows that sub-question 1 is partly answered by empirical research, and sub-question 2 and 3 almost entirely. Which bio-based materials can be used as insulation in housing renovation projects came up briefly in the exploratory interviews. The literature concluded that batts made from flax, hemp, reed and straw are currently the most appealing BBIM, and miscanthus batts and straw blow-in insulation have promising potential. The interviews revealed that choosing materials is mainly dependent on cost, ease of installation and certification. BBIM currently cost more than CIM, some of them require specialized knowledge to implement, especially in renovation, and most of them currently lack quality assurance. This shows that miscanthus batts and blow-in insulation should be stimulated more, since they could reduce material and application costs, once the expertise for it is acquired.

4.4.2 Overcoming Barriers and Using Drivers

Sub-question 2, on how barriers can be mitigated and drivers can be used effectively, is mainly answered by the barriers and drivers mentioned in this and the previous chapter. The Literature Study on barriers and drivers outlines high costs, inconsistent and low quality performance and lack of knowledge about BBIM. The Qualitative Research expands on the found barriers and drivers, highlighting the importance of policies.

The exploratory phase serves as a foundation for understanding the primary challenges faced by manufacturers, including high production costs, certification hurdles, and technical limitations such as fire resistance and thermal performance. These initial interviews also highlight opportunities, such as the growing market demand for sustainable construction materials and advancements in timber construction and recycling. The inclusion of a company that exited the BBIM market further illustrates the harsh realities of certification barriers and market competitiveness. This exploratory phase laid the groundwork for the more structured semi-structured interviews by identifying the key themes of Cost, Quality Assurance, Knowledge, and Policy.

The semi-structured interviews built on this foundation by exploring each of these four categories in depth. Cost emerged as a significant barrier, particularly for smaller companies that struggle with high production costs, certification expenses, and operational inefficiencies. However, it was also noted that larger companies often perceive these costs as strategic investments, leveraging economies of scale and optimized supply chains to gain market dominance. Quality Assurance highlighted the critical role of certifications and performance reliability, with smaller firms frequently challenged by certification costs and international regulatory discrepancies. For larger manufacturers, certifications were seen as gateways to market expansion and public tenders.

Knowledge was identified as the most frequently mentioned category, with Expertise dominating the discussion. Interviewees consistently emphasized gaps in technical understanding, market awareness, and the reluctance of the AEC industry to adapt to new materials. Training and Education emerged as essential for closing these gaps, although smaller firms often lacked the resources to implement structured learning programs. Larger companies, in contrast, frequently acquired smaller BBIM manufacturers to rapidly integrate this specialized knowledge. Finally, Policy was discussed less frequently but carried significant weight. Regulatory Frameworks were especially impactful, with interviewees describing them as hard requirements that shape market conditions. Government Incentives, although helpful, were seen as inconsistently applied and difficult to access for smaller manufacturers.

These findings are closely interconnected across the four categories. For example, CIM manufacturers are increasingly pressured by laws and regulations to develop more environmentally friendly products. One viable pathway to achieve this is by incorporating BBIM into their product lines. To do so effectively, they must acquire the necessary expertise, efficiently achieved by investing in shares of smaller BBIM companies. However, such investments are only viable if those smaller companies demonstrate consistent and reliable quality, which ties back to issues of Quality Assurance and Certification. This example illustrates that while Knowledge may be the most pressing barrier to overcome at present, the categories of Cost, Quality Assurance, and Policy are deeply interwoven and cannot be considered in isolation.

4.4.3 Innovation-driven Approach

Sub-question 3 aims to understand how innovation-driven approaches can help scale up the manufacturing of BBIM for housing renovation in the Netherlands. The findings from the qualitative research reveal that significant barriers remain in terms of Cost, Quality Assurance, Knowledge, and Policy. Addressing these challenges requires innovation-driven strategies that align with the theoretical frameworks discussed in the literature.

The Mirroring Trap highlights how the fragmented nature of the construction industry reinforces conventional material choices, hindering the uptake of BBIM. In the current project-based and decentralized market structure, manufacturers often revert to familiar materials, making it challenging for BBIM to gain market traction. To overcome this, stronger policy measures are required that encourage more integrated project delivery models. For example, public tenders and government-backed projects could set stricter sustainability requirements, mandating a percentage of bio-based materials in renovation projects. This would break the cycle of path dependency and allow BBIM to enter mainstream construction practices. Additionally, facilitating long-term partnerships between BBIM manufacturers, contractors, and housing associations could stabilize demand and normalize the use of bio-based materials. Some early steps are already visible, driven mainly by Building Balance, which actively works to connect manufacturers and market players to establish stronger, more resilient supply chains. Policymakers could further accelerate this shift by incentivizing vertical integration or design-build contracts that reward sustainable material choices.

Building on this, Rogers' Diffusion of Innovations framework provides a roadmap for increasing BBIM's visibility and market acceptance. According to Rogers, successful diffusion depends on five characteristics: relative advantage, compatibility, complexity, trialability, and observability. For BBIM, visibility of successful pilot projects and demonstration buildings would directly enhance observability and trialability, reducing perceived risks among manufacturers and contractors. In the Dutch context, several living labs and pilot projects are already testing BBIM under real-world conditions. These initiatives, although still relatively few, are slowly expanding and have started to share success stories within the sector. This early momentum needs time to mature, but it signals a positive trend towards more widespread adoption. Here, policy interventions could be particularly impactful. Subsidies for demonstration projects and incentives for collaborative learning platforms would enable stakeholders to witness the practical application and benefits of BBIM firsthand. Moreover, aligning building regulations with BBIM properties, such as accounting for their vapour permeability and environmental benefits, would improve compatibility with current building practices. Policies that streamline certification processes for BBIM and prioritize their inclusion in sustainability-focused renovation projects could further reduce complexity and enhance market trust.

Finally, SNM addresses the need for protective environments where BBIM can mature without immediate market pressures. Government-backed niche spaces, such as pilot projects and living labs, allow for experimentation and scaling without the direct risk of market failure. These protected environments not only aid manufacturers in refining production processes and achieving certifications but also foster collaborative learning among stakeholders. While many of these pilots are already underway, their true impact will become more evident as they scale up and more projects surface. Policymakers could leverage SNM principles by creating long-term funding programs that support both the development of BBIM and the necessary training for installation and application. Furthermore, policy alignment with sustainable construction goals at both national and EU levels would help solidify market demand, reducing the perceived risk for manufacturers to scale up production.

Together, these innovation theories provide a comprehensive roadmap for scaling BBIM in the Dutch renovation market, making it possible to move from isolated pilot projects to mainstream adoption. The findings suggest that innovation in BBIM manufacturing will require not just technical and financial adjustments, but a systemic shift in how construction projects are conceived, planned, and executed. Enhanced learning cycles, collaborative networks, and well-structured policy frameworks are key to bridging the gap between current capabilities and sustainable growth. The groundwork for these shifts is already being laid through initiatives by Building Balance, various living labs, and pilot projects, but broader policy support is crucial to fully realize their potential.

These findings provide a structured understanding of the barriers and drivers influencing the upscaling of BBIM in the Dutch renovation market, as well as the innovation-driven strategies required to overcome them. The application of innovation-driven strategies differs markedly between small and large manufacturers, however. Larger firms, benefiting from more extensive resources and established networks, are often able to engage in long-term partnerships and participate actively in living labs and pilot projects. For smaller manufacturers, such initiatives are often financially out of reach, underlining the importance of targeted support for these companies in innovation ecosystems. SNM can play a crucial role here, offering protected environments where smaller companies can experiment with BBIM without immediate market pressures.

The following Discussion section builds upon the insights from this chapter, critically evaluating this research, including its implications for other research in this field, the methods used and their limitations.

5 Discussion

The European Climate Pact's goals for 55% CO_2 reduction by 2030 and climate neutrality by 2050 underline the necessity for sustainable building practices, especially in the Dutch renovation sector. BBIM offer a promising alternative to CIM, with potential for significant environmental benefits, however, market penetration remains low. Through qualitative analysis of literature, exploratory interviews, and semi-structured interviews with manufacturers, this study identified key barriers and drivers for scaling BBIM in Dutch renovations, the barriers of high costs, quality assurance challenges, and knowledge gaps were confirmed and elaborated. Addressing these barriers through policy-driven innovation strategies could accelerate adoption and facilitate smoother market integration.

The initial assumption that BBIM could be easily scalable in Dutch renovations was only partially validated. While the materials themselves show strong environmental benefits, real-world adoption faces significant hurdles. Costs remain high due to limited economies of scale, certification processes are costly and complex, and there is still a lack of widespread knowledge among stakeholders about how to work with BBIM effectively. These barriers were consistent with the findings in the literature, however, the literature also presented strategies for overcoming these barriers, which were only partially observed in practice.

The study's findings suggest that while local production supports circular economy principles and reduces transport emissions, achieving cost-effectiveness and scalability might require a regional expansion strategy rather than purely local or global scaling. Given the Netherlands' small geographical size, expanding towards neighbouring markets like Germany and Belgium would be comparable to national distribution distances, minimizing CO_2 emissions while opening up larger markets.

Some interviewees suggested that BBIM and CIM might not need to operate in direct competition but could instead coexist within a more circular construction economy. BBIM could be prioritized for new materials while CIM, through circularity and recycling, could maintain its role in applications where BBIM does not yet fully meet performance requirements. This complementary approach could smooth the transition towards sustainable building practices without disrupting material availability.

5.1 Limitations

The selection of interviewees was achieved through a combination of personal connections, online searches and snowball sampling. While this approach enabled access to a diverse range of manufacturers, it may also have introduced sampling bias, as participants with stronger networks or greater visibility were more likely to be included. The study did not include perspectives from companies that exited the market during early development stages, nor from larger BBIM manufacturers. Additionally, reliance on personal networks and snowball sampling may have led to overrepresentation of certain perspectives while potentially overlooking less-connected but relevant market players. These omissions may have left certain challenges underrepresented, particularly concerning cost barriers and scalability concerns at larger production scales. Understanding the reasons for early market exits could provide insights into unseen barriers that smaller manufacturers face.

Reflecting on the findings and methods used, this study has provided a clear overview of the current state of BBIM in Dutch renovations and the barriers that limit its growth. While the qualitative nature of the study, the limited sample size of six manufacturers, and the focus predominantly on producers might have narrowed the range of perspectives, the interviews still captured valuable insights into market challenges and opportunities. Although the NMD currently lists 42 BBIM from Dutch manufacturers, it remains unclear by how many manufacturers these are produced. Among the six interviewees, only two manufacturers were based in the Netherlands, with the rest operating abroad or not directly producing BBIM. This indicates that the sample, while small, could still be somewhat representative of the Dutch BBIM market.

The qualitative approach allowed for in-depth exploration of perceptions and barriers, it inherently limits statistical generalizability. Confidence in the findings is supported by thematic consistency across interviews, yet broader quantitative validation would be required to confirm these patterns at scale. Larger-scale surveys or field experiments might provide stronger empirical evidence and enhance the robustness of the conclusions drawn.

An additional challenge faced during the research process was the difficulty in finding clear and consistent information about BBIM. This was not only identified as a barrier for market adoption but also impacted the ability to gather comprehensive data for this study. The novelty of BBIM and the lack of standardized performance metrics contribute to this inconsistency, indicating a need for more structured information-sharing platforms.

5.2 Proposed Solutions

These limitations in information and perspectives underscore the need for structured policy support and market-driven initiatives to address the barriers identified. To do this, the following policy recommendations are proposed, explicitly linked to Diffusion of Innovations and SNM:

1. Promote trialability through pilot projects to enable stakeholders to observe benefits and reduce perceived risk;
2. Strengthen observability with visible projects that demonstrate successful renovations using BBIM, increasing awareness and confidence;
3. Simplify certification pathways to reduce barriers for new manufacturers, particularly in fire safety and moisture resistance;
4. Support compatibility through policy alignment with Dutch building regulations, ensuring BBIM can be integrated into existing housing renovation projects without additional compliance burdens;
5. Enhance communication channels between manufacturers, policymakers, and construction firms to accelerate learning and market acceptance;
6. Subsidize local production and scaling efforts to stimulate economies of scale and stabilize the supply chain.

However, even if the entire construction sector were to shift towards bio-based typologies, the overall environmental impact of the sector would only be reduced by an estimated 18% (Haisma, Den Boer, Rohmer & Schouten, 2023). This underscores the need not only to transform material usage but also to critically review the demand for new housing. Strategies such as smaller housing units and the promotion of low-rise multifamily dwellings could complement bio-based innovations, ensuring the sector remains within planetary boundaries.

These policy actions are designed to systematically reduce the barriers identified in the study while improving the visibility and acceptance of BBIM in the Dutch market. However, the proposed solutions heavily depend on policy interventions, which are unpredictable and may face political or financial resistance. There is also a risk of focusing too much on those promoting BBIM and not enough on sceptics or those who are hesitant to adopt. Future research should consider these perspectives more deeply to understand resistance and address it effectively.

On top of this, while the promotion of BBIM presents clear environmental advantages, it is important to recognize that not all change is inherently positive. The large-scale shift towards bio-based construction may lead to increased pressures on agricultural land use, competition with food production, and supply chain vulnerabilities. Furthermore, the introduction of new materials into established construction practices could present unforeseen challenges, such as adaptation costs for builders and variability in performance across different climates.

Although the proposed solutions appear promising, their success is contingent upon policy alignment and market adaptation. Moving forward, it will be crucial for policymakers, manufacturers, and stakeholders to collaborate in creating an enabling environment for BBIM to thrive. This discussion sets the stage for the conclusion, where the practical implications of these findings are further explored.

6 Conclusion

The focus of this research is to explore how the use of BBIM can be stimulated in the renovation of existing housing stock in the Netherlands. In light of the European Climate Pact and the Dutch Klimaatakkoord, there is an urgent need to reduce CO_2 emissions within the built environment. Renovating existing buildings with sustainable insulation materials presents an opportunity to achieve these climate goals. This research identifies the bottleneck at the manufacturing level and investigates the main barriers and drivers that affect BBIM production and adoption. Through a combination of literature review and qualitative analysis, the study examines which bio-based materials are most suitable, what obstacles need to be addressed, and how innovation-driven strategies can facilitate upscaling.

The results can be summarized in the following way. The most promising BBIM for renovation in the Netherlands are flax, hemp, reed, and straw, with emerging potential for straw blow-in insulation and miscanthus batts. These materials are locally growable, offer good moisture-regulating properties, and perform well thermally when applied as batts. For renovation projects, these materials are particularly suitable for interior insulation, which minimizes disruption to residents and is easier to integrate into existing structures. However, these materials are currently underutilized, partly due to their higher costs compared to CIM, the specialized knowledge required for their manufacturing, and a lack of consistent quality assurance. For miscanthus and straw blow-in insulation to reach their potential, expertise in their use must be acquired and shared within the industry.

Barriers and drivers identified during the research can be categorized into four themes: Cost, Quality Assurance, Knowledge, and Policy. Among these, Knowledge emerged as the primary barrier. The lack of awareness, transparency, and technical understanding hinders the widespread adoption of BBIM. Smaller manufacturers, in particular, struggle with accessing technical expertise and market insights, while larger firms often overcome these hurdles by acquiring smaller BBIM manufacturers. Cost is a barrier mainly for smaller manufacturers who lack the economies of scale enjoyed by larger companies. High production costs, certification expenses, and raw material prices limit their market competitiveness. Larger companies view these costs more as strategic investments, using their market position to drive down costs and optimize supply chains. Quality Assurance remains a challenge, with many BBIM lacking sufficient certification and consistent performance data. Smaller firms particularly face barriers in meeting (international) regulatory requirements, while larger manufacturers often use certifications as a way to access new markets. Finally, Policy influences market conditions, yet incentives are inconsistently applied, making it difficult for smaller companies to benefit from them. Streamlined and more accessible subsidies could lower these barriers, enhancing market entry and production scaling.

In order to address these barriers and stimulate the use of BBIM in Dutch housing renovation, the study proposes three innovation-driven strategies aligned with systemic innovation theories: Mirroring Trap, Rogers' Diffusion of Innovations, and SNM. First, the Mirroring Trap emphasizes the need for long-term partnerships and more integrated project delivery models to disrupt the current reliance on CIM. Such integration is already seen in early initiatives led by Building Balance, which seeks to connect BBIM manufacturers with contractors and housing associations. Second, Rogers' Diffusion of Innovations highlights that increasing the visibility of successful BBIM projects, such as those in pilot projects and living labs, can enhance industry confidence and reduce perceived risks. Currently, these pilots are limited but growing, suggesting that more time and focused policies could expand their impact. Finally, SNM advocates for the creation of protected environments, such as living labs and government-backed niche markets, where BBIM can mature without immediate market pressures. Although many of these initiatives are already underway, more structured government support would enable BBIM to move from pilot phases to mainstream application.

The implications of these findings extend beyond individual manufacturers to the broader landscape of the AEC industry and renovation practices in the Netherlands for achieving national climate goals. Addressing the knowledge gap, in particular, is not just a matter of market readiness but a necessary step towards aligning construction practices with sustainable development. For the renovation sector, the findings highlight that integrating BBIM as standard practice is not only feasible but also a valuable asset to meet climate objectives, provided that cost barriers are mitigated, and technical expertise is disseminated more widely. Furthermore, the findings demonstrate that strategic government intervention can accelerate this transition by reducing financial risks for small manufacturers and incentivizing sustainable material choices among larger firms. This research serves as a foundation for policymakers and AEC stakeholders to co-create effective pathways for scaling BBIM, but also other innovative building materials, positioning the Netherlands as a leader in sustainable building innovation. In doing so, it also contributes to broader discussions on how localised, plant-based materials can redefine energy efficiency and circularity in the built environment.

To answer the main research question "*How can the use of bio-based insulation materials be stimulated in renovation of existing housing stock in the Netherlands?*" the findings suggest that manufacturing of BBIM needs to increase in the Netherlands. Scaling BBIM in Dutch renovations requires addressing the knowledge gap as a priority, supported by policies that enhance financial incentives, streamline certifications, and promote visible demonstration projects. Smaller manufacturers would benefit from targeted subsidies, training programs, and transparent certification pathways, while larger companies could be incentivized to integrate BBIM into their portfolios through public tenders focused on sustainability. The Dutch context provides a strong foundation for scaling BBIM due to its progressive climate policies, established sustainability goals, and a growing emphasis on circular construction practices. National initiatives, such as the Klimaatakkoord and ongoing governmental support for green building innovations, create a policy landscape conducive to the adoption of bio-based materials in renovation projects.

This growth may also require a regional expansion strategy to achieve economies of scale and stabilize supply chains, leveraging close cross-border markets such as Germany and Belgium to mirror national distribution distances. Moreover, the findings suggest that BBIM and CIM can coexist under a circular construction model, where BBIM serves new production needs while CIM, through circularity and recycling, could maintain its role in applications where BBIM does not yet fully meet performance requirements. This complementary approach could ensure material availability while smoothing the transition towards sustainable building practices. However, the shift towards large-scale BBIM production may also introduce new challenges, including pressures on agricultural land use, competition with food production, and supply chain vulnerabilities. Policy interventions must therefore not only stimulate growth but also ensure that the ecological balance is maintained. Additionally, the environmental impact of construction cannot be entirely mitigated by material shifts alone; a reduction in overall housing demand, paired with more compact and efficient housing typologies, is necessary to stay within planetary boundaries.

Ultimately, the study concludes that the use of BBIM in the renovation of existing housing stock in the Netherlands is achievable if barriers are addressed systematically and innovation is supported at both the manufacturing and policy levels. With concerted efforts to close knowledge gaps, reduce costs, improve quality assurance, and leverage effective policy instruments, BBIM can become a cornerstone of sustainable building practices in the Dutch renovation market. By focusing on structured learning, cross-sector collaboration, and long-term investment, the Netherlands can accelerate its transition to a circular, climate-resilient built environment.

7 Further Research

While this study has highlighted the key barriers and drivers for scaling BBIM in the Dutch renovation sector, several areas require further exploration to fully understand the potential and limitations of these materials. First, long-term observational studies are recommended to evaluate both the positive and negative consequences of BBIM adoption over time. Surveys alone may not capture the full range of impacts, particularly those that emerge gradually as materials age or adapt to different climatic conditions (Rogers, 2003, p. 442).

Additionally, the establishment of a centralized and reliable database containing performance metrics, certification statuses, and ecological impacts of BBIM would significantly improve transparency and market trust. This would aid manufacturers, builders, and policymakers in making more informed decisions.

Future research should also consider the ecological impacts of BBIM on vulnerable species inhabiting building structures during renovations, as outlined in RVO's documentation on after-insulation and renovations (Bankert & Van Der Sneppen, 2023). This perspective is currently underexplored and could provide insights into balancing sustainable building practices with biodiversity protection.

The scope of this study was limited to in-depth interviews with manufacturers from the Netherlands and Belgium. To gain a more comprehensive understanding of market dynamics, future studies should expand to include a broader range of European manufacturers. Moreover, engaging with larger BBIM producers could offer insights into scaling strategies, quality assurance, and market penetration that smaller manufacturers currently struggle with. There is also little insight into the barriers and drivers of manufacturers that reject BBIM, or have stopped producing BBIM. This could also be expanded upon.

Comparative analyses between localized production models and broader European networks could also shed light on the cost efficiency and scalability of BBIM in different market conditions. Field-based experiments are recommended to validate the thermal and environmental performance of BBIM in Dutch climate conditions, providing empirical evidence to support policy advocacy and market growth.

While Rogers' Diffusion of Innovations and Strategic Niche Management provided useful frameworks for understanding the diffusion of BBIM, exploring alternative innovation theories may uncover new pathways for market integration and scalability. That way, a deeper understanding of the systemic changes required to integrate BBIM into the mainstream renovation sector could be provided.

These avenues for further research not only aim to fill existing knowledge gaps but also support the broader ambition of making BBIM a viable and sustainable standard in Dutch renovations. By expanding the scope of investigation to include long-term impacts, ecological considerations, and broader European insights, the path towards scalable, climate-resilient bio-based construction becomes clearer. A coordinated effort in research, policy, and market integration will be essential for realizing the full potential of BBIM, contributing to a sustainable and circular built environment.

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Appendix A – Interview Consent Form

Promoting the use of bio-based insulation materials in renovation of existing housing stock

Good morning/afternoon,
Thank you for participating in this interview. This research is conducted by me, Valerie Erd, as a part of my master thesis for the Management in the Built Environment track at the TU Delft.

<u>Goal of this interview</u>
The goal of my research is to gain insight into what drives or hinders companies in manufacturing Biobased Insulation Materials. Through this interview I would like to know how the company started, and what barriers or drivers emerged throughout its history.
The aim of this interview is to analyse which factors boost innovation, and more specifically the manufacture of Biobased Insulation Materials, and which stand in its way.

<u>Structure of this interview</u>
This interview will take approximately 1-1,5 hours. Due to the time limitation, I ask you to keep your answers to the point, and I may remind you of this if I feel like we are running out of time.
The questions of this interview will first start with introductory questions to gain insight into your company, after which I will continue with questions about the three main barriers I have found (cost, quality assurance and knowledge) and possible drivers for increasing the manufacture of biobased insulation materials. Lastly, I wish to know if there are any insights I may have missed up till now.

<u>Consent</u>
I would like to ask your consent to record this interview. Afterwards it will be transcribed and your name and any contact details will be removed. You will be sent the transcript (if applicable, translated into English) within 2 weeks after the interview to review, before it is finalised. After you have received the transcript, you will have another 2 weeks to voice any comments. After this time has passed, your consent to the transcript will be assumed. You are still allowed, at any time, to withdraw this consent. The risk of a data breach is always possible, but to remove as much risk as possible, the recording of this interview will be deleted after transcription. The transcripts will be stored on my TU Delft OneDrive. At the end of my thesis all personally identifiable data will be deleted within one month of completion. The derived data as part of my thesis will be uploaded to the TU Delft repository, where it will be publicly accessible.

Your participation in this research is entirely voluntary, and you may withdraw or amend your statements at any time. You are also free to leave questions unanswered for any reason. In case you wish to withdraw your consent, your data will be removed within one month of receiving your request, and it will not be used in my thesis.

If you consent to the interview as I have described it to you, I would kindly ask you to fill in the boxes starting on the next pages and sign the form at the bottom. You will receive a copy of this signed consent form via email.

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICPANT TASKS AND VOLUNTARY PARTICIPATION		
1. I have read and understood the study information dated [DD/MM/YYYY], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
3. I understand that taking part in the study involves:	☐	☐
The student *records* this interview. Afterwards it will be *transcribed* and my name and any contact information will be removed. I will be sent the *transcript* (if applicable, translated into English) to review, before it is finalised. The risk of a data breach is always possible, but to remove as much risk as possible, the recording of this interview will be *deleted after transcription*. My name on the transcript will be removed and the transcript will be stored on the student's TU Delft OneDrive. At the end of the student's thesis all personally identifiable data (interview transcripts, consent forms, contact information, ATLAS.ti documents) will be deleted within one month of completion, and the findings and conclusions in the thesis will be shared publicly.		
4. I understand that the study will end after the student has completed their thesis. Completion is reached after the student is accredited with the marks regarding their thesis in the TU Delft interface. It is anticipated that the thesis will be completed in June 2025.	☐	☐
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
5. I understand that taking part in the study involves risks regarding professionally sensitive information. I understand that these will be mitigated by being asked for approval of the transcribed interviews, before they can be used as data.	☐	☐
6. I understand that taking part in the study also involves collecting specific personally identifiable information (PII): interviewee name, work address, company name and email address, and associated personally identifiable research data (PIRD) with the potential risk of my identity being revealed: audio recordings (temporary), transcripts, professional opinions on barriers and drivers for increasing production of biobased insulation materials, occupation, city & country of company location and company size. The risks of re-identification are mitigated as much as possible by the data being stored in separate folders on OneDrive, and by being anonymised as much as possible. The raw data (interview transcripts, consent forms, contact information, ATLAS.ti documents) will not be shared after project completion.	☐	☐
7. I understand that the following steps will be taken to minimise the threat of a data breach, and protect my identity in the event of such a breach: data will be anonymised as much as possible and not shared publicly, audio recordings will be deleted and everything will be stored on OneDrive, behind 2FA.	☐	☐
8. I understand that personal information collected about me that can identify me, such as my name, work address, company name and email address will not be shared beyond the study team.	☐	☐

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
9. I understand that the (identifiable) personal data I provide will be destroyed within one month after the student has completed their thesis. Completion is reached after the student is accredited with the marks regarding their thesis in the TU Delft interface. It is anticipated that the thesis will be completed in June 2025.	☐	☐
C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		
10. I understand that after the research study the de-identified information I provide will be used for the master thesis of Valerie Erd, expanding on decision-making, policies and collaboration regarding the promotion of bio-based insulation materials in renovation of existing housing stock.	☐	☐

Signatures

_____________________________ _____________________________ _________

Name of participant [printed] Signature Date

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

_____________________________ _____________________________ _________

Researcher name [printed] Signature Date

If you have questions or complaints, feel free to contact either me:

Valerie Erd
[Email Address]
[Phone Number]

Or one of my supervisors:

Henk Visscher
[Email Address]

Erwin Mlecnik
[Email Address]

Appendix B – Exploratory Interview Notes

Is it OK if I record?

- Introductions
- Explaining research
- Purpose: this conversation to further explore knowledge gaps lie

<u>Questions:</u>

What did you do before BBIM?
How did you first hear about BBIM?
How did you orient yourselves about BBIM?
Were there decisive things that made you take the step to production?
Were there any difficulties in starting production/starting sales?
Do you notice a lot of demand for your product? From which kind of group?
How do you see the trend of BBIM going?

Why don't you use a different BBBM?
Are there things you could/would have done better in a different way?
Were there external factors that stood in your way/helped you?

(If applicable) No subsidy yet, what is the problem?
Is there different legislation in the Netherlands to the one abroad?
How do other companies respond to BBIM?

Appendix C – Interview Questions

C.1 Only producing BBIM

Only producing BBIM - English

Part 1: Introduction

1. Could you introduce yourself and explain what your role in the company is?
2. What is the main product your company produces?
3. Why did you choose this material? Are you also looking into other biobased materials?
4. Are your products used in renovation of existing housing stock?
5. What was the driving force behind the establishment of your company?
6. How big is the company? Do you see it growing in recent and upcoming years?

Part 2: Cost

7. How did you overcome the initial investment costs? What was the biggest hurdle, and how did you overcome it, in terms of cost?
8. What benefit made the new product worth the risk? How much did profit factor into this decision?
9. Currently bio-based insulation materials are generally more expensive in retail than fossil-based insulation. How do you overcome this?

Part 3: Quality Assurance

10. How do you ensure consistency in your product without surrendering the proportion of bio-based material?
11. In my research I have found that legal product requirements are difficult to meet for bio-based insulation material. How did you manage this? Do you have an idea for an adjustment that would make inclusion of bio-based insulation material easier?

Part 4: Knowledge

12. To what extent do properties of bio-based materials lead to opportunities or obstacles? - e.g. fire resistance, breathability, insulation value, ...
13. How did you acquire the expertise for producing bio-based insulation materials? And what about expertise on how to apply the finished product in (renovation) projects?
14. I have found that not everybody in the built environment is familiar with the properties of BBIM, which results in reluctance to choose these products. What efforts do you make to increase familiarity with your products among other stakeholders? What has the biggest impact?

Part 5: Drivers

15. To what extent do you think the following factors affect the choice to produce bio-based insulation materials? And what do you think is necessary for them to become (bigger) drivers for the production of bio-based insulation material?
    a. Certifications, (beoordelingsrichtlijnen)
    b. Laws and regulations, (bouwbesluit)
    c. Subsidies (carbon credits for manufacturers, energiebespaarlening for end-users)
16. Do you feel like communication and organisation from the government about their strategies to reach climate goals is clear? How does the government influence your choice to work with biobased materials?
17. How would you describe the cooperation between you and other stakeholders, and do you feel like your partners (principal, architect, contractor) support innovation?
18. Who is the main client for your product? Is it what you expected?

Part 6: Closing

19. In your opinion, are there important barriers or drivers I have failed to mention?
20. What do you think is the main barrier for the manufacturing of bio-based insulation materials? What do you think should be done to overcome this barrier?

21. In the same vein, what do you think is, or could be, the main driver for the manufacturing of bio-based insulation materials?
22. Is there anything else you would like to mention?
23. May I contact you again if I have further questions?

Produceren alleen BBIM – Nederlands

Deel 1: Inleiding

1. Kun je jezelf voorstellen en uitleggen wat je rol in het bedrijf is?
2. Wat is het belangrijkste product dat jullie bedrijf produceert?
3. Waarom hebben jullie voor dit materiaal gekozen? Kijken jullie ook naar andere bio-based materialen?
4. Worden jullie producten gebruikt bij de renovatie van bestaande woningen?
5. Wat was de drijvende kracht achter de oprichting van jullie bedrijf?
6. Hoe groot is het bedrijf? Zien jullie het bedrijf groeien in de afgelopen en komende jaren?

Deel 2: Kosten

7. Hoe hebben jullie de initiële investeringskosten overwonnen? Wat was het grootste hindernis en hoe hebben jullie die overwonnen, in termen van kosten?
8. Welk voordeel maakte het nieuwe product het risico waard? In hoeverre speelde winst een rol in deze beslissing?
9. Op dit moment zijn bio-gebaseerde isolatiematerialen over het algemeen duurder in de detailhandel dan fossiele isolatie. Hoe overkomen jullie dit?

Deel 3: Kwaliteitsgarantie

10. Hoe zorg je voor consistentie in je product zonder in te leveren op het aandeel bio-based materiaal?
11. In mijn onderzoek heb ik ontdekt dat het moeilijk is om te voldoen aan wettelijke productvereisten voor bio-based isolatiemateriaal. Hoe hebben jullie dit voor elkaar gekregen? Hebben jullie een idee voor een aanpassing die het opnemen van bio-based isolatiemateriaal makkelijker zou maken?

Deel 4: Kennis

12. In welke mate leiden eigenschappen van bio-based materialen tot kansen of obstakels? - bv. brandwerendheid, ademend vermogen, isolatiewaarde, ...
13. Hoe hebben jullie de expertise verworven voor het produceren van bio-based isolatiematerialen? En hoe zit het met expertise over hoe het eindproduct toe te passen in (renovatie)projecten?
14. Ik heb gemerkt dat niet iedereen in de gebouwde omgeving bekend is met de eigenschappen van BBIM, wat resulteert in terughoudendheid om voor deze producten te kiezen. Welke inspanningen doen jullie om de bekendheid van jullie producten bij andere stakeholders te vergroten? Wat heeft de grootste impact?

Deel 5: Drijfveren

15. In hoeverre denken jullie dat de volgende factoren van invloed zijn op de keuze om bio-based isolatiematerialen te produceren? En wat is er volgens jullie nodig om deze factoren (grotere) drijvende krachten te laten worden voor de productie van bio-based isolatiemateriaal?
    a. Certificeringen (beoordelingsrichtlijnen)
    b. Wet- en regelgeving (bouwbesluit)
    c. Subsidies (koolstofkredieten voor fabrikanten, energiebespaarlening voor eindgebruikers)
16. Hebben jullie het gevoel dat de communicatie en organisatie vanuit de overheid over hun strategieën om klimaatdoelen te bereiken duidelijk is? Hoe beïnvloedt de overheid jullie keuze om met bio-based materialen te werken?

17. Hoe zouden jullie de samenwerking tussen jullie en andere stakeholders omschrijven, en hebben jullie het gevoel dat jullie partners (opdrachtgever, architect, aannemer) innovatie ondersteunen?
18. Wie is de belangrijkste klant voor uw product? Is het wat u verwachtte?

Deel 6: Afsluiting

19. Zijn er volgens jullie belangrijke barrières of drijfveren die ik niet heb genoemd?
20. Wat is volgens jullie de belangrijkste barrière voor de productie van bio-based isolatiematerialen? Wat moet er volgens jullie gedaan worden om deze barrière te overwinnen?
21. In dezelfde geest, wat is of zou volgens jou de belangrijkste drijfveer kunnen zijn voor de productie van bio-based isolatiematerialen?
22. Is er nog iets anders dat je zou willen noemen?
23. Mag ik opnieuw contact met jullie opnemen als ik nog verdere vragen heb?

C.2 Adopted BBIM (a little)

Adopted BBIM (a little) – English

Part 1: Introduction

1. Could you introduce yourself and explain what your role in the company is?
2. What is the main product your company produces?
3. Which biobased materials are you currently using? Why this one? Are you also looking into other biobased materials?
4. Are your products used in renovation of existing housing stock?
5. What was the driving force behind the establishment of your company?
6. How big is the company? Do you see it growing in recent and upcoming years?

Part 2: Cost

7. To what extend does cost influence your decision to use bio-based materials?
8. What made choosing bio-based materials worthwhile, and what would make adding more bio-based materials worthwhile? Not only in terms of cost, but also other benefits.

Part 3: Quality Assurance

9. To what extend does quality assurance influence your decision to use bio-based materials?
10. Which material properties would make it worthwhile to invest (more) in bio-based materials?

Part 4: Knowledge

11. To what extend does information about bio-based materials influence your decision to use it?
12. How did you acquire the expertise for incorporating bio-based insulation materials?
13. How accessible do you think information about bio-based materials is? How could this be improved? Which information is most difficult to obtain?

Part 5: Drivers

14. To what extent do you think the following factors affect the choice to produce bio-based insulation materials? And what do you think is necessary for them to become (bigger) drivers for the production of bio-based insulation material?
    a. Certifications, (beoordelingsrichtlijnen)
    b. Laws and regulations, (bouwbesluit)
    c. Subsidies (carbon credits for manufacturers, energiebespaarlening for end-users)
15. Do you feel like communication and organisation from the government about their strategies to reach climate goals is clear? How does the government influence your choice to work with biobased materials?
16. How would you describe the cooperation between you and other stakeholders, and do you feel like your partners (principal, architect, contractor) support innovation?
17. Who is the main client of your products? Do you expect that they would also adopt bio-based insulation materials?

Part 6: Closing

18. In your opinion, are there important barriers or drivers I have failed to mention?
19. What do you think is the main barrier for the manufacturing of bio-based insulation materials? What do you think should be done to overcome this barrier?
20. In the same vein, what do you think is, or could be, the main driver for the manufacturing of bio-based insulation materials?
21. Is there anything else you would like to mention?
22. May I contact you again if I have further questions?

(Een beetje) BBIM opgenomen – Nederlands

Deel 1: Inleiding

1. Kun je jezelf voorstellen en uitleggen wat je rol in het bedrijf is?
2. Wat is het belangrijkste product dat jullie bedrijf produceert?
3. Welke bio-based materialen gebruiken jullie op dit moment? Waarom deze? Kijken jullie ook naar andere bio-based materialen?
4. Worden jullie producten gebruikt bij renovatie van bestaande woningen?
5. Wat was de drijvende kracht achter de oprichting van jullie bedrijf?
6. Hoe groot is het bedrijf? Zien jullie het bedrijf groeien in de afgelopen en komende jaren?

Deel 2: Kosten

7. In hoeverre beïnvloeden de kosten jullie beslissing om bio-based materialen te gebruiken?
8. Wat maakte de keuze voor bio-based materialen de moeite waard, en wat zou het toevoegen van meer bio-based materialen de moeite waard maken? Niet alleen in termen van kosten, maar ook in termen van andere voordelen.

Deel 3: Kwaliteitsgarantie

9. In hoeverre beïnvloedt kwaliteitsborging jullie beslissing om bio-based materialen te gebruiken?
10. Welke materiaaleigenschappen zouden het de moeite waard maken om (meer) te investeren in bio-based materialen?

Deel 4: Kennis

11. In hoeverre beïnvloedt informatie over bio-based materialen jullie beslissing om ze te gebruiken?
12. Hoe heb je de kennis opgedaan om bio-based isolatiematerialen te gebruiken?
13. Hoe toegankelijk is informatie over bio-based materialen volgens jullie? Hoe zou dit verbeterd kunnen worden? Welke informatie is het moeilijkst te verkrijgen?

Deel 5: Bestuurders

14. In welke mate zijn de volgende factoren volgens jullie van invloed op de keuze om bio-based isolatiemateriaal te produceren? En wat is er volgens jou nodig om deze factoren (grotere) drijvende krachten te laten worden voor de productie van bio-based isolatiemateriaal?
    a. Certificeringen (beoordelingsrichtlijnen)
    b. Wet- en regelgeving (bouwbesluit)
    c. Subsidies (koolstofkredieten voor fabrikanten, energiebespaarlening voor eindgebruikers)
15. Hebben jullie het gevoel dat de communicatie en organisatie vanuit de overheid over hun strategieën om klimaatdoelen te bereiken duidelijk is? Hoe beïnvloedt de overheid jullie keuze om met bio-based materialen te werken?
16. Hoe zouden jullie de samenwerking tussen jullie en andere stakeholders omschrijven, en hebben jullie het gevoel dat jullie partners (opdrachtgever, architect, aannemer) innovatie ondersteunen?
17. Wie is de belangrijkste klant van uw producten? Verwacht je dat zij ook bio-based isolatiematerialen zouden gaan gebruiken?

Deel 6: Afsluiting

18. Zijn er volgens jullie belangrijke barrières of drijfveren die ik niet heb genoemd?
19. Wat is volgens jullie de belangrijkste barrière voor de productie van bio-based isolatiematerialen? Wat moet er volgens jullie gedaan worden om deze barrière te overwinnen?
20. In dezelfde geest, wat is of zou volgens jou de belangrijkste drijfveer kunnen zijn voor de productie van bio-based isolatiematerialen?
21. Is er nog iets anders dat je zou willen noemen?
22. Mag ik opnieuw contact met jullie opnemen als ik nog verdere vragen heb?

C.3 Not (yet) producing BBIM

Not (yet) producing BBIM - English

Part 1: Introduction

1. Could you introduce yourself and explain what your role in the company is?
2. What is the main product your company produces?
3. Have you looked into any bio-based materials? Why this one? Are you also looking into other biobased materials?
4. Are your products used in renovation of existing housing stock?
5. What was the driving force behind the establishment of your company?
6. How big is the company? Do you see it growing in recent and upcoming years?

Part 2: Cost

7. To what extend does cost influence your decision to use bio-based materials?
8. What would make choosing bio-based materials worthwhile? Not only in terms of cost, but also other benefits.

Part 3: Quality Assurance

9. To what extend does quality assurance influence your decision to use bio-based materials?
10. Which material properties would make it worthwhile to invest (more) in bio-based materials?

Part 4: Knowledge

11. To what extend does information about bio-based materials influence your decision to use it?
12. How did you acquire the expertise for (potentially) incorporating bio-based insulation materials?
13. How accessible do you think information about bio-based materials is? How could this be improved? Which information is most difficult to obtain?

Part 5: Drivers

14. To what extent do you think the following factors affect the choice to produce bio-based insulation materials? And what do you think is necessary for them to become (bigger) drivers for the production of bio-based insulation material?
    a. Certifications, (beoordelingsrichtlijnen)
    b. Laws and regulations, (bouwbesluit)
    c. Subsidies (carbon credits for manufacturers, energiebespaarlening for end-users)
15. Do you feel like communication and organisation from the government about their strategies to reach climate goals is clear? How does the government influence your choice to work with biobased materials?
16. How would you describe the cooperation between you and other stakeholders, and do you feel like your partners (principal, architect, contractor) support innovation?
17. Who is the main client of your products? Do you expect that they would also adopt bio-based insulation materials?

Part 6: Closing

18. In your opinion, are there important barriers or drivers I have failed to mention?
19. What do you think is the main barrier for the manufacturing of bio-based insulation materials? What do you think should be done to overcome this barrier?

20. In the same vein, what do you think is, or could be, the main driver for the manufacturing of bio-based insulation materials?
21. Is there anything else you would like to mention?
22. May I contact you again if I have further questions?

Produceren (nog) geen BBIM:

Deel 1: Inleiding

1. Kun je jezelf voorstellen en uitleggen wat je rol in het bedrijf is?
2. Wat is het belangrijkste product dat jullie bedrijf produceert?
3. Welke bio-based materialen gebruiken jullie op dit moment? Waarom deze? Kijken jullie ook naar andere bio-based materialen?
4. Worden jullie producten gebruikt bij renovatie van bestaande woningen?
5. Wat was de drijvende kracht achter de oprichting van jullie bedrijf?
6. Hoe groot is het bedrijf? Zien jullie het bedrijf groeien in de afgelopen en komende jaren?

Deel 2: Kosten

7. In hoeverre beïnvloeden de kosten jullie beslissing om bio-based materialen te gebruiken?
8. Wat maakte de keuze voor bio-based materialen de moeite waard, en wat zou het toevoegen van meer bio-based materialen de moeite waard maken? Niet alleen in termen van kosten, maar ook in termen van andere voordelen.

Deel 3: Kwaliteitsgarantie

9. In hoeverre beïnvloedt kwaliteitsborging jullie beslissing om bio-based materialen te gebruiken?
10. Welke materiaaleigenschappen zouden het de moeite waard maken om (meer) te investeren in bio-based materialen?

Deel 4: Kennis

11. In hoeverre beïnvloedt informatie over bio-based materialen jullie beslissing om ze te gebruiken?
12. Hoe heb je de kennis opgedaan om bio-based isolatiematerialen te gebruiken?
13. Hoe toegankelijk is informatie over bio-based materialen volgens jullie? Hoe zou dit verbeterd kunnen worden? Welke informatie is het moeilijkst te verkrijgen?

Deel 5: Bestuurders

14. In welke mate zijn de volgende factoren volgens jullie van invloed op de keuze om bio-based isolatiemateriaal te produceren? En wat is er volgens jou nodig om deze factoren (grotere) drijvende krachten te laten worden voor de productie van bio-based isolatiemateriaal?
    a. Certificeringen (beoordelingsrichtlijnen)
    b. Wet- en regelgeving (bouwbesluit)
    c. Subsidies (koolstofkredieten voor fabrikanten, energiebespaarlening voor eindgebruikers)
15. Hebben jullie het gevoel dat de communicatie en organisatie vanuit de overheid over hun strategieën om klimaatdoelen te bereiken duidelijk is? Hoe beïnvloedt de overheid jullie keuze om met bio-based materialen te werken?
16. Hoe zouden jullie de samenwerking tussen jullie en andere stakeholders omschrijven, en hebben jullie het gevoel dat jullie partners (opdrachtgever, architect, aannemer) innovatie ondersteunen?
17. Wie is de belangrijkste klant van uw producten? Verwacht je dat zij ook bio-based isolatiematerialen zouden gaan gebruiken?

Deel 6: Afsluiting

18. Zijn er volgens jullie belangrijke barrières of drijfveren die ik niet heb genoemd?
19. Wat is volgens jullie de belangrijkste barrière voor de productie van bio-based isolatiematerialen? Wat moet er volgens jullie gedaan worden om deze barrière te overwinnen?

20. In dezelfde geest, wat is of zou volgens jou de belangrijkste drijfveer kunnen zijn voor de productie van bio-based isolatiematerialen?
21. Is er nog iets anders dat je zou willen noemen?
22. Mag ik opnieuw contact met jullie opnemen als ik nog verdere vragen heb?

Appendix D – ATLAS.ti code co-occurences of quotations

	Cost	Quality Assurance	Knowledge	Policy
Barriers (132)	45	42	66	29
Drivers (133)	39	45	59	38
Both	3	3	4	2
Total	81	84	121	65

Appendix Table 1 – Co-occurrence of quotation codes in ATLAS.ti (own work)

	Certification Costs	Investment Costs	Operational Costs	Production Costs	Cost (Total)
Barriers	5	24	7	20	45
Drivers	3	27	6	9	39
Both	3	3	1	3	3
Total	5	48	12	26	81

Appendix Table 2 – Co-occurrence of "Cost" quotations in ATLAS.ti (own work)

	Certifications	Performance and Reliability	Quality Assurance (Total)
Barriers	6	37	42
Drivers	12	37	45
Both	0	3	3
Total	18	71	84

Appendix Table 3 – Co-occurrence of "Quality Assurance" quotations in ATLAS.ti (own work)

	Expertise	Training and Education	Knowledge (Total)
Barriers	62	8	66
Drivers	44	21	59
Both	4	1	4
Total	102	28	121

Appendix Table 4 – Co-occurrence of "Knowledge" quotations in ATLAS.ti (own work)

	Government Incentives	Regulatory Frameworks	Policy (Total)
Barriers	3	26	29
Drivers	12	28	38
Both	1	1	2
Total	14	53	65

Appendix Table 5 – Co-occurrence of "Policy" quotations in ATLAS.ti (own work)

Appendix E – ATLAS.ti code co-occurrences filtered by company size

E.1 Costs

	Barrier 132	Drivers 133
Cost 81	34	25
Cost: Certifica... 5	5	3
Cost: Investm... 49	17	13
Cost: Operati... 12	6	7
Cost: Producti... 26	13	8

	Barrier 132	Drivers 133
Cost 81	16	26
Cost: Certifica... 5		
Cost: Investm... 49	9	21
Cost: Operati... 12	2	2
Cost: Producti... 26	9	4

Appendix Figure 1 – Costs Small vs Large Companies

E.2 Quality Assurance

	Barrier 132	Drivers 133
Quality (Assur... 84	25	27
Quality (Assur... 18	5	6
Quality (Assur... 71	21	22

	Barrier 132	Drivers 133
Quality (Assur... 84	27	21
Quality (Assur... 18	6	7
Quality (Assur... 71	21	17

Appendix Figure 2 – Quality Assurance Small vs Large Companies

E.3 Knowledge

	Barrier 132	Drivers 133
Knowledge 121	36	44
Knowledge: E... 102	31	31
Knowledge: T... 28	8	19

	Barrier 132	Drivers 133
Knowledge 121	37	24
Knowledge: E... 102	34	20
Knowledge: T... 28	4	4

Appendix Figure 3 – Knowledge Small vs Large Companies

E.4 Policy

	Barrier 132	Drivers 133
Policy 66	18	19
Policy: Govern... 14	1	7
Policy: Regula... 54	17	13

	Barrier 132	Drivers 133
Policy 66	18	22
Policy: Govern... 14	3	6
Policy: Regula... 54	15	18

Appendix Figure 4 – Policy Small vs Large Companies

Appendix F – AI Declaration

For this research, AI was used in the following manner. I used Microsoft Copilot to clean up the transcripts from the interviews I conducted. Since Copilot is generally considered safe to process personal data, I have uploaded the transcripts written by Microsoft Teams, and prompted it to keep the speakers, times and shared information in tact. I have then checked the transcripts with the recordings, to make sure the information stayed the same.

I have also used Chat GPT in order to assist me in understanding concepts, generating sentence structure and checking whether I have left out any important information. For concepts, I have prompted Chat GPT to explain them, allowing me to ask further questions to acquire a better understanding. For sentence structure I wrote down a collection of my thoughts, after which I could spar with Chat GPT how best to structure my thoughts and which choice of words to use. I have also asked Chat GPT to inform me if it thought I was missing important information. This information was sometimes helpful, but often I did not include optional information in favour of brevity.

Appendix G – Reflection

My graduation project is closely related to my master track MBE within the MSc AUBS programme, as it addresses the intersection of sustainability, innovation, and the built environment. Throughout my studies, I have explored the challenges and opportunities associated with making the construction industry more sustainable, and this project is a direct extension of that. By focusing on bio-based building materials (BBIM) and their role in decarbonizing the built environment, I have been able to bridge the gap between theoretical knowledge from my coursework and practical applications in the field. This exploration of market dynamics, policy influence, and sustainable innovations ties directly into the MBE programme's emphasis on integrating sustainability into construction practices.

The MSc AUBS programme's focus on sustainable development, innovation, and global perspectives also influenced my research direction. Specific courses from the MBE track, like Research Methods 1 and 2 (RM1, RM2) and Building Law, prepared me with the necessary skills to conduct qualitative research, set up interview structures, and analyse policy frameworks. RM1 introduced me to the Mirroring Trap concept, which I could apply in my analysis, while RM2 provided practical experience in conducting interviews and using ATLAS.ti for qualitative data analysis.

Throughout my thesis, the research and design decisions were influenced by an iterative loop of learning and refinement. I am a perfectionist, so I find it difficult to do iterative processes, instead wanting to do it correctly the first time. Of course, this is almost never possible, so it is a continuous learning process for me, with plenty of practice moments. Once I got over my personal hurdle of not wanting to touch text that I thought was finished, I was able to improve my thesis, by being more flexible to move into other directions, and by adding information wherever necessary. One example of this is the codes I used in ATLAS.ti. Initially, I structured my ATLAS.ti codes around the themes of cost, quality assurance, knowledge, and drivers. However, as I conducted interviews and engaged with feedback from my supervisors, it became evident that 'policy' was a crucial and recurring theme. This realization led me to adjust my coding structure, allowing for a more comprehensive analysis of barriers and drivers. This iterative process ultimately allowed me to refine my research focus and include more critical perspectives. I had to remind myself regularly to also process information that I did not like or that contradicted my assumptions. This was a learning process that broadened my perspective and deepened my analysis.

However, reflecting back, I recognize that my interviews could have been more effective if I had asked 'why' more frequently. During the analysis of the transcripts, it became clear that I often moved to the next question instead of probing deeper into the reasoning behind certain barriers and drivers. I also noticed afterwards that there may have been miscommunications when I asked about "certificates", when I actually meant "declarations", such as EPDs. This means that interviewees sometimes discarded the importance of certificates, because they are necessary before entering the market anyway. They also then did not mention importance of optional declarations as drivers for demand. I also feel like I haven't even touched the tip of the iceberg when it comes to understanding the full complexity of BBIM adoption and market dynamics.

I have talked a lot with my supervisors about the scope of my research, of course. They advised me to interview more stakeholders, rather than only manufacturers, which I resisted, because I feared it would broaden my scope too much and complicate the analysis. In the end, the information I received from renovation professionals turned out to be incredibly insightful, so I regret not having included more of those. This could also mean that I missed valuable insights from other stakeholders which I completely disregarded. Although I am proud of maintaining a focused scope, I recognize in hindsight that there was likely a middle ground that I did not explore.

Working with my supervisors throughout the thesis process taught me to balance external input with my own decision-making. At the last meeting with my supervisors, I received input on how to structure my discussion, which helped me bring it from a weak section on small limitations, to a discussion where I included validation, critical reflection on my methods and what it meant that I used these specific innovation theories. While I stood firm on narrowing my scope, their encouragement to explore different perspectives broadened my understanding of market barriers and policy influences. Their feedback not only improved the structure and depth of my analysis but also gave me the confidence to keep pushing forward when I felt lost. This mentorship created a healthy balance of guidance and independence, allowing me to make this research truly my own.

The decision to conduct semi-structured interviews with BBIM manufacturers provided valuable qualitative insights that would not have been captured through literature review or surveys. Speaking directly with manufacturers allowed me to understand real-world barriers and drivers from their perspective, particularly regarding market dynamics, policy influences, and production challenges. This qualitative approach enabled me to explore specific themes in depth and adjust the interview flow based on emerging insights.

However, the limited number of interviewees, combined with the use of snowball sampling, resulted in a relatively narrow view of the BBIM market. While I do not believe that snowball sampling introduced significant biases, it may have restricted the diversity of perspectives, especially from larger manufacturers and international players. Furthermore, during the analysis of the interview transcripts, I noticed that I missed opportunities to ask deeper 'why' questions. More probing questions could have uncovered underlying motivations and barriers more effectively, highlighting the need for improved interview techniques. I also found that I could have organized my email outreach better, as I sometimes mixed up contacts or missed follow-ups. Standardizing my communication process would have made the recruitment process smoother.

The findings of this research are primarily rooted in the Dutch context, yet they hold significant transferability potential for other Western European countries. The barriers I identified (cost, quality assurance and knowledge) are not unique to the Netherlands, and my recommendations to overcome these can be adapted to other countries with similar policy landscapes such as Germany, Belgium and Denmark. Additionally, my findings could be useful beyond BBIM, as they highlight broader themes in sustainable material adoption that apply to various aspects of the built environment.

However, the scalability of BBIM may face different challenges in regions with differently developed policy frameworks or weaker governmental support. For example, I talked to one interviewee about change under dictatorships, which facilitate change at a faster pace, but that would also bring all the negative side effects that are possibly mitigated by a slower introduction. If insulation manufacturers had to change from CIM to BBIM from one day to the next, for example, their business would suffer without having the time or space to change even if they wanted to. This means, in my eyes, that while the Dutch government is too restricted to facilitate fast changes, this is also so they can happen within set boundaries that are made to protect. I feel, however, that change should stem from the government, as policies can have as much and as little power as governments give them.

During the writing of my thesis I have also had time to work on my own development. I have needed some more time than is intended for a master thesis at MBE. However, during my journey I have learned a lot about how to regulate my personal time, how to manage a large (and often overwhelming) project, and how and when to ask for help. I have, of course, learned a lot about the subject of this thesis, and how to conduct research from beginning to the end (and I found out I would rather leave it to others). I have learned how to communicate professionally with companies in the Netherlands and abroad, and that other people can be as driven as I am about getting large companies to make environmentally healthy choices. I have learned more about my strengths (being more comfortable with interviews than I expected, being overly curious about material innovations) and weaknesses (sometimes being too precise, preferring teamwork over solo-work). These are developments I hope to take with me into my future career.

Finally, I feel like research can go on forever. Even though, at times, this felt like my life's work, this is "merely" a master thesis. There was a limited time-frame, and I have only read about renovation and spoken to interviewees about the practicalities, but this does not make me an expert. Perhaps vapour open building does not work in reality, even though it should, on paper. With more time come more insights, so I feel like this thesis could be expanded upon forever. For now, however, I would like to conclude this thesis, and wish other researchers the best of luck with their endeavours.

Additional Reflection Questions:

1. Did my interview questions allow for other outcomes than this? Was the focus too much on "Knowledge" and did this therefore emerge as the most important factor?
2. Should I have manifested the increase of BBIM more in the wording of my thesis? For example, I used "Conventional" as the antonym for "Bio-based", but this also works on the premise that BBIM are not *conventional* insulation materials.