The role of public procurement in the transition of bio-based construction materials in The Netherlands

Sustainable Business and Innovation

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Abbreviations

CEAP- Circular Economy Action Plan

EDG- European Green Deal

GHG- Green House Gas

GPP- Green Public Procurement

IS- Innovation System

MIA- Milieu Investeringsaftrek

MIS - Mission Oriented Innovation System

MLP- Multi-Level Perspective

MPG- Milieu Prestatie Gebouwen

MRA- Metropole Region Amsterdam

PP- Public Procurement

SDG- Sustainable Development Goals

TIS - Technological Innovation System

TT- Technological Transition

Abstract

The Netherlands have set the goal to have a 100% circular economy by the year 2050. This includes sustainable production and the use of renewable materials.

The construction sector is one of the sectors where current processes cause a large amount of Greenhouse gas (GHG) emissions. Implementation of bio-based construction materials provides a possible solution for the reduction of the environmental footprint of the sector. Scaled-up processes are essential for the effectiveness regarding the reduction of the environmental footprint. However, these materials have currently a small market share. According to the European Commission, the procurement power of public authorities can serve as a driver for sustainable products. Green Public Procurement is a demand stimulating policy tool for sustainable innovations and therefore gives the possibility to stimulate market formation for biobased construction materials in the Dutch construction sector.

The transition of biobased construction materials in the Dutch market is defined as technological change, whereby the TIS framework is used to identify drivers and barriers in this transition. In addition, the role of public procurement is included in the analysis to identify the barriers hampering stimulating sustainable products. Data on both the processes have been obtained from literature and interviews with experts of the innovation system.

The findings show that knowledge exchange, guidance of the search and resource mobilization form the main barriers in this transition. Knowledge exchange is lacking between different actors in system causing uncertainties and misconceptions regarding these materials. Also, the national policies used in building processes have shown to be not in favour of biobased construction materials and therefore shows limited guidance for the development of the technology. This results in limited financial resources to stimulate the developments of scaling up the technology. Moreover, the findings have shown that the current public procurement as a demand-stimulating tool does not stimulate these sustainable innovations sufficiently, as the processes are based on conventional construction methods. This is also hampered by the national policies, in which changing these policies is seen as a time costly process, hampering acceleration of the transition.

Therefore, it can be concluded that the transition can be accelerated focusing on market formation whereby the procurement process should adapt to a new approach of tendering. Market formation can influence guidance of the technology as policies can adapt with changing markets. This can result in reinforcement of the other functions and thus can accelerate the transition of biobased construction materials in the Dutch construction sector.

Executive summary

The Dutch construction sector contributes to a major part of the greenhouse gas (GHG), in the Netherlands. The Dutch government has set the goal to build 100% circular in 2050, in which 50% of the GHG emission must be reduced (Rijksoverheid, 2018b). Overall, the construction sector generates 35% of the EU total waste, whereby this sector uses high emission intensive processes.

Alternative materials are essential to reduce the environmental footprint of the sector. A possible solution is the substitution of conventional materials with biobased construction materials. These materials have shown many benefits for buildings and residences (Pittau et al., 2018). Bio-based materials are renewable resources consisting of the ability to sequestrate carbon and can be obtained from local areas (Heidari et al., 2019). Using bio-based materials in construction can store these emissions during the whole lifetime which can result in the reduction of CO_2 in the atmosphere (Arrigoni et al., 2017).

Therefore, the aim of this study is to focus on the implementation and the scale-up of bio-based construction materials within the Dutch construction sector. The following research question has been put forward.

How can the transition towards a circular construction sector by scaling up bio-based construction materials be accelerated in The Netherlands?

Currently, the biobased construction materials represent a small share in the Dutch market whereby demand is limited. Nevertheless, according to the European Commission (2020), green public procurement (GPP) can serve as a driver for the market formation of sustainable products. GPP can play a major role in market formation of bio-based construction materials in The Netherlands, if the current procurement process by public authorities is modified. A second research question has therefore been formulated as follows:

How can public procurement by the Dutch municipalities and housing corporations stimulate sustainable market formation in order to accelerate the transition towards of bio-based construction materials?

To provide the answers to these research questions, the framework Technological Innovation System (TIS) proposed by Hekkert et al. (2011), is used to identify drivers an barriers in the transition of the biobased construction materials. In addition, GPP has been integrated in this framework to the function market formation, in which the steps necessary to accelerate the transitions and to adapt the current procurement process can be identified.

The findings of this research show that knowledge exchange, guidance of the search and resource mobilization form the main barrier for this innovation system and therefore hamper acceleration the transition. In terms of knowledge exchange, the lack of knowledge causes uncertainties for both supply and demand in the innovation system regarding the development of the technology. In addition, the knowledge obtained from pilot projects is not translated into a strategy which can stimulate further development. To improve knowledge exchange among the actors of the innovation system. This can be realized in the form a platform or database which provides the information needed regarding these materials. In addition, it is recommended to focus on the inclusion of biobased building techniques and methods of educational programmes and the possibilities for retraining current employers in the construction sector.

The current policies of the Dutch construction sector are also not in favour of biobased construction materials and therefore gives limited guidance. This forms a barrier for the market to invest in these materials for further scaled-up processes. It is therefore recommended to focus on the possibilities to stimulate market formation via housing corporations and municipalities, due to the time costly process to adapt national policies.

Regarding resource mobilization, financial resources are limited and therefore entrepreneurs cannot invest in improving the technology. Additionally, human resources in terms of skilled labour is lacking, which is essential in the development of the technology. In terms of resources mobilization, financial resources should be provided by the Dutch government in the form of subsidies or changes

in the compulsory landlord levy. However, due to the limited guidance given for this technology, subsidies are yet not sufficiently available. Other suggestions given are therefore to analyse the possibilities for combining the building budget. Biobased construction materials are distinguished by their CO_2 storage, it is therefore recommended to analyse the possibilities for attaching a financial value to this, which can stimulate the acceleration of the implementation of biobased construction materials in the Dutch market.

Based on the function analyses is has been seen that the public procurement process insufficiently stimulates demand for this innovation. As beforementioned, a barrier is identified regarding the national construction policies, which hamper to choose these materials. Subsequently, the specifications for buildings projects are generally written in detail and based on conventional building techniques. This results in that they are difficult to deviate from and hampers implementing other materials. Therefore, to increase demand by public actors for biobased construction materials, it is recommended to broaden the support for these materials within the internal organisation of public actors. A suggestion given is the link to the sustainable development goals (SDGs), which demonstrate the benefits of biobased construction materials for the different climate objectives. Another approach which has shown to be effective in stimulating sustainable materials is the adaption of tenders in which boundary conditions/specific objectives (e.g., CO2 storage) are given for the building projects. This provides opportunities for the entrepreneurs to invest in their business.

In addition, this study has focused on the role of public procurement, however the transition requires a whole system change of which public procurement is part. Moreover, the findings show that public procurement only refers to housing corporations. Dutch municipalities have a different role in building projects of residential areas in which their procurement process is not involved. The effectiveness of this tool therefore depends on the performance of other elements in the system to stimulate sustainable innovations. Further research therefore can be conducted on the effectiveness of other demand stimulating policy tools for stimulating sustainable innovations in a static socio-technological regime.

This research has focused on the transition of biobased construction materials in the Dutch construction sector, whereby an in-depth analysis is given on the demand side of the innovation system. Further research can be conduction on the opportunities for Dutch farmers in providing the raw materials. The agriculture sector is dealing with climate challenges affecting their business. The scale-up of biobased construction materials can create a new business case for Dutch farmers in which their environmental footprint can be reduced.

In addition, the use of biobased construction materials can be defined as one of the innovations that contributes to the mission of a 100% circular economy. Additional research can be conducted using the framework 'Mission-Oriented Innovation System (MIS)' proposed by Hekkert et al. (2020), whereby the analysis of behavioural and organisational change has been included (Hekkert et al., 2020). Based on the findings of this study these elements are essential for the transition towards a circular/biobased construction sector. Lastly, research can be conducted on the role of private actors in the scale-up of this technology, as both housing corporations and private actors form the demand side of the innovation system and therefore both should be included in stimulating the scale-up of biobased construction materials.

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1. Introduction

The European Green Deal (EGD) has been introduced by the European Commission to overcome the threat of climate change and environmental degradation, which currently affects the world. Therefore, the EGD strives for a sustainable economy in which Europe becomes the first continent with net zero emissions in 2050. The EGD is a growth strategy which aims to *"transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy"* (European Commission, 2019, p.2) in which resource use and economic growth will be decoupled. As part of the EGD, the Circular Economy Action Plan (CEAP) has been introduced which provides a future-oriented agenda for a cleaner and competitive Europe (European Commission, 2020). Additionally, the European Commission introduced a 'sustainable product policy legislative initiative' which broadens the eco-design directives beyond energy-related (European Commission, 2020).

One of the priorities given in this legislative are high impact intermediary products, which include steel, cement and chemicals. The construction sector generates 35% of the EU total waste. Furthermore, this sector uses high emission intensive processes which produce 5-12% of the total national greenhouse gas (GHG) emissions. These processes consist of material extraction, manufacturing of construction products, construction and renovation of buildings. Moreover, both direct and indirect CO_2 emission of buildings are still rising due to the use of electricity and commercial heat which have generated 10Gt CO_2 in 2019 (IEA, n.d.). The construction sector is therefore the largest sector with regard to environmental pollution. Rising CO_2 emissions will continue due to the use of fossil fuel-based materials, lack of effective energy-efficiency policies and insufficient investment in sustainable buildings (IEA, n.d.). Improvement of the material efficiency could save 80% of those emissions (European Commission, 2020). That is why the European Commission has set goals to increase the material efficiency within the construction sector and reduce the impact on global climate.

To stimulate circularity within this sector, the EU will launch a 'Strategy for a Sustainable Built Environment' and has already updated the 'bioeconomy Action Plan' , supporting the sustainable and circular bio-based sector (European Commission, 2020). One of the objectives of the EU's Bioeconomy action plan is "*reducing dependence on non-renewable, unsustainable resources whether sourced domestically or from abroad*" (European Commission, 2018, p. 9). The transition towards a bio-based economy can substitute the current non-renewable resources, which is in line with the EU's commitment to the Paris Agreement (European Commission, 2018). Subsequently, a bioeconomy contributes to the strengthening and modernisation of the EU industrial base by reducing fossil fuel-based processes in major industries, including the construction sector. Within this sector, understanding is increasing on the importance of sustainable bioeconomy activities such as the given potential for carbon sequestration, substitution of fossil-based materials with bio-based materials, improved resource efficiency and the reduction of GHG emissions (European Commission, 2018).

According to The Dutch government (Rijksoverheid, 2018a), a link has been established between the transition agenda for a circular economy and bioeconomy policies which state to improve the bioeconomy in many sectors. The main goals the Dutch government has set to achieve a Circular economy are the reduction of raw materials by using them more efficiently, using sustainably produced renewable materials and stimulating the development of new production methods and circular products (Ministerie van Infrastructuur en Waterstaat, 2019). For the construction sector specifically, the Dutch government has set the goal to build 100% circular in 2050 (Rijksoverheid, 2018b) and a reduction of 49% of the CO2 by 2030 compared to 1990 (Ministerie van Infrastructuur en Waterstaat, 2021a).

Studies have shown that the use of bio-based materials within the construction sector lowers the GHG emissions over the whole life cycle (Dodoo, 2019). However, much of the research conducted on bio-based materials focuses on the application of timber in which other bio-based materials such as wood fibres (e.g. hemp, flax, reed, bamboo and straw) are limited. However, Pittau

et al. (2019) stated that carbon sequestration will show significant effectiveness in the contribution to the Paris agreement targets using both wood and plant-based fibres. Therefore, this study will focus on the implementation and the scale-up of bio-based construction materials in the broad sense within the Dutch construction sector. The following research question is put forward:

How can the transition towards a circular construction sector by scaling up bio-based construction materials be accelerated in The Netherlands?

The transition towards the use of bio-based materials in the Dutch construction sector is part of a technological transition consisting of complex processes. Hekkert et al. (2011) proposed a framework in which the structure of the technological innovation system (TIS) and the 'functions of innovation systems' are evaluated. Both the structure and the system functions are important elements which determine the performance of innovation system (Hekkert et al., 2011). This study will focus on the processes of these functions in which drivers and barriers will be identified. Within this research, an in-depth analysis will be conducted on the role of public procurement in the process of market formation of bio-based construction.

According to the European Commission, the procurement power of public authorities can serve as a driver for sustainable products, as this represents 14% of EU gross domestic product (GDP) (European Commission, 2020). Green Public Procurement (GPP) is a policy tool which has high potential for the decarbonization of the economy and improving sustainable development (Chiappinelli & Zipperer, 2017). Furthermore, GPP is one of the main policy tools used in the construction sector for office buildings, to reduce both the environmental impact and improve the environmental and innovative value of sustainability in the economy (Braulio-Gonzalo & Bovea, 2020). GPP has therefore the ability to enlarge the market for bio-based products and services (Cheng et al., 2018). One of the key activities of the Dutch government to stimulate a circular economy is encouraging sustainable procurement to improve sustainable market demand (Rijksoverheid, 2018a). Despite high ambitions to implement environmental targets in the procurement decisions, data have shown that these targets still play a limited role in award decisions. In 2019, only 35.2% of the tenders were awarded based on environmental criteria (Bouwend Nederland, 2020).

GPP can play a major role in market formation of bio-based construction materials in The Netherlands, if the current procurement process by public authorities is modified. A second research question is therefore formulated as follows:

How can public procurement by the Dutch municipalities and housing corporations stimulate sustainable market formation in order to accelerate the transition towards of bio-based construction materials?

Results of this study contribute to the analysis of innovations within strong socio-technical regimes of standardisations and policies. Furthermore, this study contributes to the literature gap of the role of GPP in acceleration of sustainable innovations as an integrated element of the TIS. Both theories are conceptualized in one framework in which barriers of the transition and the steps needed to stimulate market formation of sustainable innovations can be identified. Furthermore, studies have been conducted on the system analysis for the transition on circular business cases for the Dutch construction sector (Beumer et al, 2021). This study therefore fills the gap by focusing on system analysis of biobased construction materials in the Netherlands. Creating a market for bio-based construction material in the Netherlands, can contribute to the Dutch societal challenges, which includes climate objectives of 100% circularity in 2050, the energy transition, carbon/nitrogen crisis and housing crisis.

The following structure for this report has been followed. In the next chapter, the theory on biobased construction materials is described, followed by detail information on the theories used for the system analysis. The fourth chapter illustrates the conceptual framework of the combined

theories. The following chapter, the methodology is describes followed by findings, in which they are discussed in chapter 7. Last, the answers on the research questions combined with recommendation are given.

2. Biobased construction materials

The construction sector is facing several challenges regarding its environmental footprint. Bio-based construction materials can partially resolve these current environmental impacts (Krasny et al., 2017; Pacheco-Torgal et al., 2020). Bio-based materials such as timber have been used in the construction sector for a long time, but are undermined by the use of steel and reinforced concrete (Pacheco-Torgal et al., 2020). However, bio-based materials, including wood and plant-based fibres, have shown many benefits for buildings and residences and meet the interest of stakeholders because of performance, moderate costs and on-site assembly (Pittau et al., 2018). Bio-based materials are renewable resources consisting of the ability to sequestrate carbon and can be obtained from local areas. (Heidari et al., 2019). An important characteristic of bio-based materials is negative emissions. During the growth of bio-based materials, CO_2 emissions from the atmosphere are absorbed and stored by photosynthesis and therefore can be categorised as negative emissions (Jiang et al., 2020). Using bio-based materials in construction will store these emissions during the whole lifetime of the product and reduce the CO_2 emissions in the atmosphere (Arrigoni et al., 2017).

The energy performance of existing buildings is part of the new European regulations in which the primary energy demand needs to be reduced. Insulation of buildings plays an important role in the energy demand for keeping a desirable temperature in buildings. Bio-based insulation materials show a suitable substitution for the current insulation materials. A major advantage of using bio-based materials is the ability to form a breathable wall due to the ability of moisture buffering capacity regulating indoor relative humidity (Seng et al., 2017; Jiang et al ., 2020). The hygric buffer characteristic of these materials reduces the demand for energy for regulating the indoor temperature (air-conditioning and heating) improving the living comfort (Jiang et al., 2020). Furthermore, conventional building material are a major contribution to indoor emissions of volatile organic compounds, and therefore affects the indoor quality. Substitution of non-renewable composites with nature-based materials were can reduce the pollutants of indoor air. The use of these materials can improve the air quality as the amount of volatile organic compounds emitted by the insulation material will be reduced (Khoshnava et al., 2020).

According to different studies, biobased construction materials have a positive effect on both physical and mental health of the occupants. This relates to biophilia, which defines the need for connection between humans and nature. It has been seen in these studies that work efficiency and satisfaction improve when working in a green building. This has been linked to the indoor air quality, thermal comfort and (day) lighting. Furthermore, the study shows that this can have positive effects on the organisational costs due to reduced illness (less absenteeism), increased job performance and reduced stress (World Green building council, 2014; Lowe, 2020).

The environmental impact of products and materials can be measured with a Life Cycle Assessment (LCA), a tool accordance ISO 14040/14044 (Heidari et al., 2019). LCA quantifies the environmental impacts of the whole life cycle regarding the energy and material chain and as such can play a decisive role in identifying possibilities for the energy reduction and climate impacts of buildings (Dodoo, 2019). In the Dutch construction sector, sustainability of buildings is measured according to Environmental performance of Buildings (Milieuprestatie gebouwen, MPG). Criteria have been set for the environmental impact of the buildings. The value of MPG is based on the values of the LCAs of the materials. To construct a certain building in the Netherlands, the value of the MPG cannot exceed the shadow costs of 1.0 per unit of product (Rijksdienst voor ondernemend Nederland, 2020).

3. Theory

3.1 Technological Innovation System

The transition of bio-based construction materials can be categorized as a technological transition. Geels (2002) defines Technological Transitions (TT) as *"major technological transformations in the way societal functions [..] are fulfilled"* (P.1287), which involve changes in different elements of the current societal regime. The development of bio-based construction materials occurs in the niche phase of the MLP framework and is therefore the focus of this study. The emergence of niches strongly depends on the current regimes and the socio-technical landscape. The developments within the higher levels of the MLP, will determine the success of the innovations. Pressure on the regime caused by external landscape developments will create disturbance, tensions and windows of opportunity for niches to break through as shown in figure 1 (Geels, 2002). The Figure shows that the TT does not only include the technology and market share, but implementation in the regime also depends on changes in regulation, infrastructure and industrial networks (Geels, 2002). Hekkert et al. (2007) states that analysis of the dynamics of these innovations is important for the understanding of technological change. To analyse innovations in the niche-level the concept of *innovation systems* (IS) has been proposed to demonstrate all actors, societal subsystems and institutions which influence the development and diffusion of a technology into the current regime. However, this concept mainly focuses on a macro-level perspective (institutions) instead of entrepreneurs (micro-level). The analysis focuses on quasi-static innovation systems and is lacking on the dynamics of the innovation systems. To obtain a better understanding and guidance of the direction of the technological change in the innovation system, a dynamic innovation system approach is required.

Hekkert et al. (2007) proposed a framework which describes the dynamics of the transition of technologies within a socio-technical system or 'regime'. The framework of the dynamics of technological change is defined as the 'Technological Innovation System', in which the main focus is the technology. In order to have an understanding of the incentive of the technological change, analysis of the system dynamics over time will give a better understanding of the mechanisms and patterns of the technological change (Hekkert et al., 2007). This analysis is important for the development of policies regarding the technology.

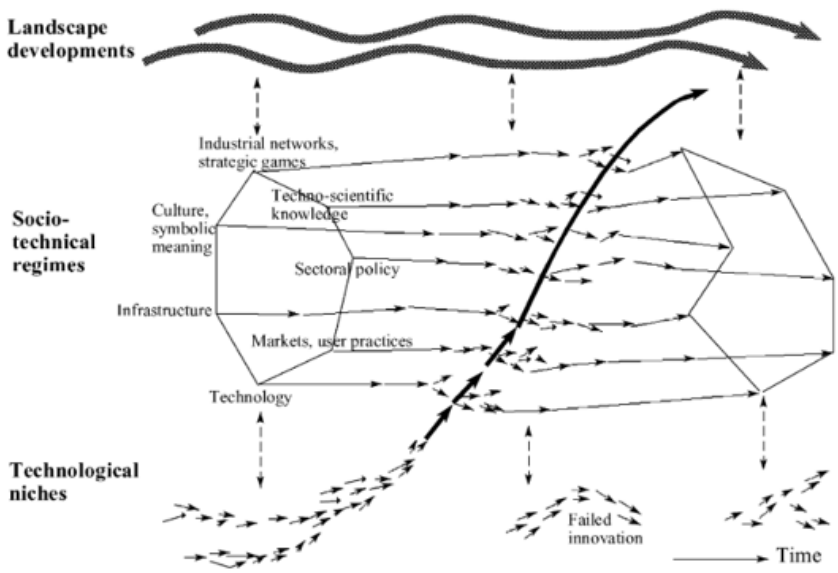


Figure 1: The visualization of the dynamics of a technological transition from the niche phase into the existing socio-technical regime (Geels, 2002, p. 1263).

The TIS has a system structure which consists of different components. Interrelations within this system structure are fundamental for the transition of the technology. The components of the system are characterized by actors, institutions, networks and technologies which make up the structure of the innovation system. To give a detailed overview of the structure of the innovation system of the technology, the components are categorized in different elements as shown in Figure 2. Identifying the system structure of the new technology determines which components are present in the structure and which components are still missing to build a well-functioning system (Hekkert et al., 2011).

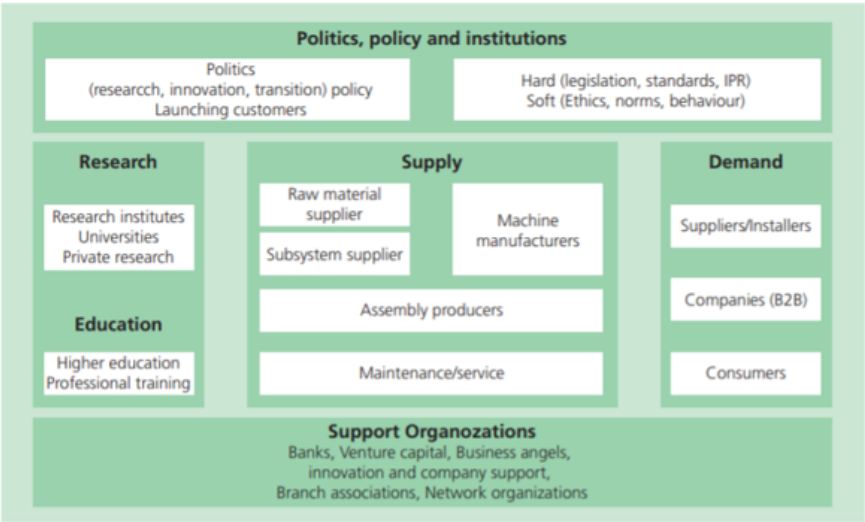


Figure 2: The innovation structure (Hekkert et al., 2011, p. 5).

The transition of a technology diffuses through four different stages of development; *pre-development, development phase, take-off phase and acceleration phase* in which the functioning and structure of the technology differs in each phase. The extent to which the technology diffuses through these phases is illustrated by a S-shaped curve (Figure 3a) (Hekkert et al., 2011)

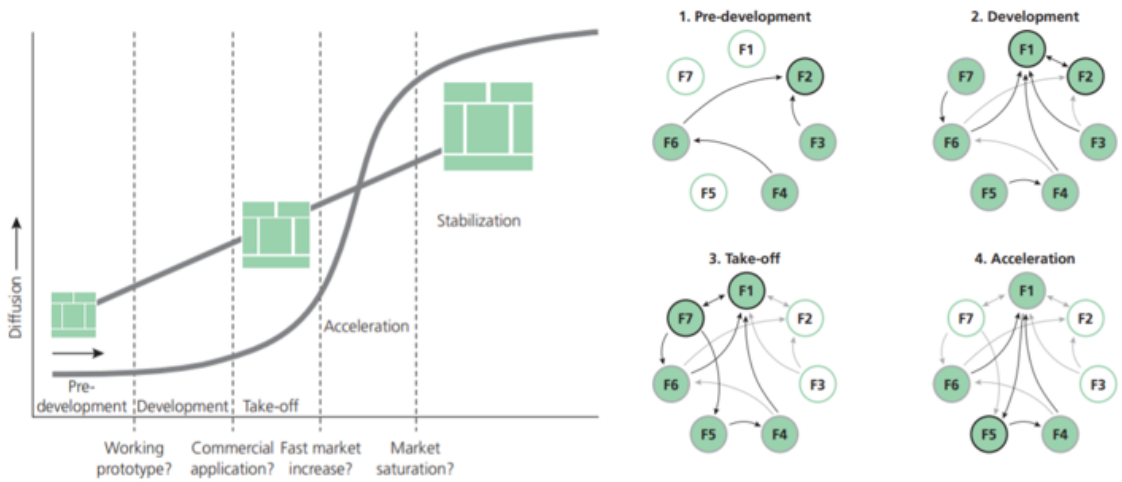


Figure 3: A) The stages of development of a new technology (Hekkert et al., 2011, p. 9). B) The important system functions for each phase of development (Hekkert et al., 2011, p. 12).

The shift of the technology depends on 'the key processes of the innovation system' which are defined as 'System Functions' and are interrelated with each other in the system (figure 3b, table 1). The functions describe '*how*' the system is performing and evaluates the dynamics of the transition of the technology (Hekkert et al., 2007; Hekkert et al., 2011).

Table 1: The characteristics of the key processes of the innovation system (Hekkert et al., 2007).

Function	Characterization
F.1 Entrepreneurial activities	*The presence of entrepreneurial activities gives an indication of the innovation system's performance,*
F.2 Knowledge development	*Mechanisms of knowledge development (e.g. R&D, market research) are fundamental for innovation processes.*
F.3 Knowledge exchange	*Exchange of knowledge with the key actors in system of the technological transition is crucial for stimulating the acceleration of the transition in to the existing system.*
F.4 Guidance of the search	*The activities which have a positive effect on both visibility and clarity of the specific demand among technology users and thus decreases risk precipitation of the technology.*
F.5 Formation of markets	*Creating protecting market space for new technologies to improve knowledge and expectations as innovation often do not fit in the current socio-technical regime.*
F.6 Mobilization of resources	*Human and financial resources are necessary to conduct the activities within the innovation system and accelerate the transition.*
F.7 Counteracting resistance to change	*Create legitimacy and therefore counteract the resistance to change is important for new technologies to be implemented in the existing regime.*

The performance of the system depends on the fulfilment of the system functions. All functions interact with each other in the system and therefore are able to reinforce each other both positively and negatively. Hekkert et al. (2007) describes that the interactions of the functions form a vicious circle. Different paths can be followed to form this circle. Possible starts are identification of societal problems which are translated into governmental goals (F4). Another possibility is the lobby by entrepreneurs for improved economic conditions for the development of the technology which can increase expectations (F7). Lastly, entrepreneurs can *"lobby for market formation since very often a level playing field is not present[..]. When markets are created, a boost in entrepreneurial activities (F1) is often visible leading to more knowledge formation (F2), more experimentation (F1), and increased lobby (F7) for even better conditions and high expectations that guide further research (F4)"* (p. 426).

A well performing system can be built up when all functions are (sufficiently) fulfilled. However, vicious cycles can occur when negative function fulfilment results in weakly performance of other functions and thereby negatively influence to transition of the technology (Hekkert et al., 2007).

Functions which are not sufficiently fulfilled are hampered by barriers regarding the development of the technology. Therefore, identifying the phase of development determines the

important functions that need to be fulfilled to shift the technology to the next phase of development (Figure 3b) (Hekkert et al., 2007; Hekkert et al., 2011).

3.3 (Green) public procurement

Diffusion of innovations in the system can be influenced by both the demand of private and public organisations. As this study focuses on the scale- up of bio-based construction materials, the concept of public procurement (PP) defined by Rainville (2016) as *"the acquisition of goods or services by public entities''* will be addressed. PP is an important demand-side innovation policy tool for encouraging innovations regarding the mitigation of societal challenges and the transformation of socio-technical systems (Cayolla Trindade et al., 2017). The formation of markets for innovations is a dynamic system of interacting elements (Individuals, businesses or organisations) which carries, uses, acquires and generates knowledge through learning. According to Bleda & Chicot (2020), PP has a knowledge coordinating function within the different stages of market formation processes. Public authorities are able to orchestrate system innovations using public procurement which can encourage the market formation of new technologies, products and services.

Subsequently, the power of PP can be a driver for the development of sustainable markets (Cayolla Trindade et al., 2017). Sustainable consumption and production have become a prime societal mission in order to reduce the climate impact of the current consumption and production patterns (Edquist & Zabala-Iturriagagoitia, 2012; Rainville, 2016). To stimulate sustainable innovations, the policy tool GPP which defines the *"[P]urchasing which reduces environmental impacts across product or service life cycles''* (Rainville, 2016, p. 1029) has been introduced by the European Commission aiming for the reduction of the climate impact of products through their whole lifecycle. Furthermore, GPP stimulates technological innovations among businesses and influences market acceleration of sustainable products (Bleda & Chicot, 2020).

Public authorities are able to influence products regarding material use and energy efficiency as well as transparency in the supply chain (Alhola et al., 2018). According to Cayolla Trindade et al. (2017), public procurement for innovations requires a different approach compared to the regular off-the-shelf goods in which coordination is important to enhance the effectiveness of this policy instrument.

The study of procurement of bio-based construction materials for the Dutch construction sector can be categorized as procurement of innovations. Standards play an important role in the adaptation of the innovation and the decisions of public authorities to commercialize innovations (Rainville, 2016).

As defined by Hsueh et al. (2020), standards are *"a set of documented rights, duties and procedures that reach a wider set of organisational actors in a consistent manner"* (p. 700). The degree of adaptation of innovative solutions relates to the compatibility with the existing infrastructure of the current system (Rainville, 2016; Hsueh et al., 2020). Standards are used to test the compatibility of the innovation with the existing infrastructure which reduces the costs of adaptive solutions and prevents incompatible interfaces (Rainville, 2016).

As further stated by Hsueh et al. (2020) procurement choices are based on meeting the needs and demand of the public organisations with limited operating budget. Therefore, market diffusion of innovative solutions will be more rapid when being procured using the correct reference to existing standards (Rainville, 2016). For the uptake of GPP, comprehensive and clear operation rules are needed to govern the inclusion of environmental criteria in the procurement process. Important rule are technical specifications, which is prerequisites to submit a tender (Uttam & Le Lann Roos, 2015). An indicator for managing environmental concerns is the uptake of environmental criteria in technical specifications and the use of ecolabels in the procurement process (Testa et al., 2012; Uttam & Le Lann Roos, 2015; Hsueh et al., 2020).

Furthermore, procurement occurs by routines developed for many products by local authorities which are based on formulized patterns (Hsueh et al., 2020). This also applies for construction services and transportation/fuels. Including environmental criteria in procurement processes requires changes in the existing organisational routines of the procurement process. Procurement behaviour of public procures must change in order to obtain green procurement processes. However, procurers tend to prefer past processes due to previous policies and therefore to avoid risky innovative projects to prevent legal conflicts (Grandia, 2016). Nevertheless, changes in the procurement routines can be stimulated by compliance and intrinsic belief of stakeholders in GPP (Lăzăroiu et al., 2020).

Another aspect which determines the procurement process is decision-making criteria, in which multiple factors will ensure trade-offs in the process. This is indicated by award criteria, which *"[E]nable the procurer to compare the relative advantages of different tenders by giving weights to the criteria and scoring each tender on the basis of the level of fulfilment of each criterion"* (Uttam & Le Lann Roos, 2015, p. 404). Another indicator is the access to information on the environmental impact of products (Hsueh, et al., 2020). According to Heidari et al. (2019), lack of data on the environmental impact can influence the decisions of customers and decision makers and therefore their understanding can be lacking on the impact of their choices. One of the common decision-making criteria is the procurement cost. In GPP processes, criteria related to environmental impact of products are considered, including minimization of packaging waste, improved reuse and recyclability of the products and reducing GHG emissions and disposal costs.

The rules and standards, routines and the decision-making criteria are important aspects of the public procurement process of products and therefore play a major role in the market formation of innovations in a socio-technical system (Hsueh et al., 2020).

4. Conceptual framework

This research includes both theories of the TIS and GPP for the analysis of the transition and scale-up of bio-based construction materials in the Dutch construction sector. The current regime of the construction sectors plays a major role in the transition of new technologies (Franzini et al., 2018). The function analysis can give detailed information on the dynamics in the niche phase of the biobased construction materials. According to Hekkert et al. (2011), public procurement policy tool can stimulate the transition of new technologies into the existing socio-technical system, which demands mechanism is shaped by standards and rules, routines and decision-making criteria (Hsueh et al., 2020).

The focus of this study is the scale-up of biobased construction materials in the current Dutch construction sector. Prototypes are in place regarding these materials in both the Netherlands and neighbouring countries. However, scale-up processes are missing. Therefore, the function market formation plays a role in further transition of these materials.

The function market formation (F.5) of the TIS framework can be linked to GPP, as this a policy tool is used to stimulate sustainable markets. It is important that the policy tool stimulates sustainable technologies and therefore prioritizes environmental criteria. By integrating the current aspects of the GPP process in the TIS framework, barriers of the system functions causing the system to fail, can be further linked to the aspects of GPP (Table 2). The reason for neglection of environmental criteria in the procurement processes in the Dutch construction sector can then be identified.

With the findings of both concepts, policy recommendation can be given on the steps needed to accelerate the transition of biobased construction materials and the modification the current public procurement aspects in the Dutch construction sector and thus improving the 'Green' in PP decision criteria. The external impact of GPP on the TIS can then stimulate market demand for sustainable technologies in the current socio-technical regime.

Table 2: Green public procurement intergraded in the system function of market formation (F.5) including the indicators defining GPP (Hekkert et al., 2011; Testa et al., 2012; Uttam & Le Lann Roos, 2015; Hsueh et al., 2020; Heidari et al., 2019; Lăzăroiu et al., 2020).

Function	Indicator (s)
F5. Market Formation	*-Project installed in existing regime*
F5.1 *Green Public procurement*	
Rules and Standards	*-Environmental technical specifications* *-Environmental standards (e.g. Use of ecolabels)*
Routines	*-Organizational and behavioural change* *-Routines associated with ecological criteria in operational phase* *-key stakeholders embracing GPP*
Decision - making criteria	*- Environmental criteria part of award criteria* *- Access to information*

5. Methodology

5.1 Research design

The research on the transition of bio-based construction materials was a qualitative research approach in which a case study design was used (Brymann, 2016). The five steps of the TIS analysis were followed throughout this research. This method was chosen as it evaluates the dynamics of a transition of an innovation within the existing socio-technical system. The goal was to identify barriers hampering the transition and provide policy recommendation to stimulate the market for sustainable innovations in static socio-technical systems.

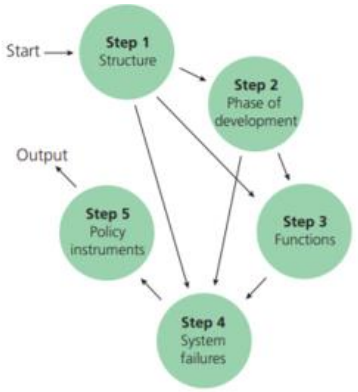


Figure 4: Five step analysis of the TIS framework for policy recommendations (Hekkert et al., 2011, p.4)

5.2 Data collection

Data collection for this research consisted of different parts. A triangulation approach was used in which different methods are applied to collect data. Using different methods prevents bias and improves the dynamics in the findings.

First, literature research was conducted on the innovation system of bio-based construction materials and the aspects of (standards and rules, routines and decision-making criteria) of the procurement processes of the Dutch construction sector. The current procurement processes and the criteria and targets of GPP for the Dutch construction sector were researched. The literature review consisted of scientific articles, governmental reports and grey literature. Data sources used to collect literature were Google Scholar, governmental databases and Nexis Uni[1]. Research was conducted using the following search terms: “Biobased construction materials” OR “Biobased building materials” AND “green public procurement” OR “public procurement” AND “Netherlands OR “Dutch” AND “Construction policies” OR “Building policies “.[2]

In the second part of the research, data was collected for the analysis for the TIS and the use of GPP as policy tool to stimulate the market formation. Interviews were conducted to collect data in order to determine the functioning of the innovation system. The interviewees were chosen based on the main actors of the system structure of the innovation system which play a major role in the scale up of these materials (table 3). This includes municipalities and housing corporations as these actors play a role in tendering for building projects and therefore forming a major part the demand side of the innovation system. Furthermore, intermediaries, project developers and architects were chosen to gain data on the technology and the system as a whole. Lastly, governmental institutes and organisations were included to collect data on the role of the policies within the sector and the transition of new materials.

[1] https://www.uu.nl/en/university-library/help-in-searching/search-engines-explained/nexis-uni.
[2] The search terms are also used in Dutch.

Table 3: Overview of interviewees and their role in the innovation system

Reference	Function of expert
Expert 1	Intermediary
Expert 2	Intermediary
Expert 3	Intermediary
Expert 4	Dutch Government/ Intermediary
Expert 5	Dutch Government
Expert 6	Province
Expert 7	Province
Expert 8	Province
Expert 9	Province
Expert 10	Municipality
Expert 11	Municipality
Expert 12	Municipality
Expert 13	Municipality
Expert 14	Housing corporation
Expert 15	Housing corporation
Expert 16	Housing corporation
Expert 17	Housing corporation
Expert 18	Architect
Expert 19	Architect
Expert 20	Project developer
Expert 21	Knowledge institute

The sampling strategy used was a combination of convenient (network of the company) and snowball (recruited by interviewee) strategy. The interviews were based on a semi-structured interview, in which an interview guide was used as a guideline during the interviews (Brymann, 2016). The interview guide followed the order of the functions as shown in table 4, in which the diagnostic questions for each function of the TIS was used to improve the generalizability of the findings.

Data collection for GPP was included in the same interview guide. In the section 'market formation', specific questions were asked related to the GPP. The goal of these questions was to gather data on the three aspects (Standards and rules, routines and decision-making criteria) of the current procurement process and use of environmental criteria (Appendix- I). The indicators as formulated in table 2, which define these processes were used to formulate open questions.

The interviews were conducted via Microsoft Teams or Zoom and are transcribed using Listen and Write program and Trint.

Table 4: The system functions and the diagnostic questions for the analysis of the performance of the innovation system (Hekkert et al., 2011, p. 10)

Functions and indicators	Diagnostic questions
F1 - Entrepreneurial Experimentation and production - Actors present in industry (from structural analysis)	- Are these the most relevant actors? - are there sufficient industrial actors in the innovation system? - do the industrial actors innovate sufficiently? - do the industrial actors focus sufficiently on large sale production? - Does the experimentation and production by entrepreneurs form a barrier for the Innovation System to move to the next phase?
F2 - Knowledge Development - Amount of patents and publications (from structural analysis)	- Is the amount of knowledge development sufficient for the development of the innovation system? - Is the quality of knowledge development sufficient for the development of the innovation system? - Does the type of knowledge developed fit with the knowledge needs within the innovation system - Does the quality and/or quantity of knowledge development form a barrier for the TIS to move to the next
F3 - Knowledge exchange - Type and amount of networks	- Is there enough knowledge exchange between science and industry? - Is there enough knowledge exchange between users and industry? - Is there sufficient knowledge exchange across geographical borders? - Are there problematic parts of the innovation system in terms of knowledge exchange? - Is knowledge exchange forming a barrier for the IS to move to the next phase?
F4 - Guidance of the Search - Regulations, Visions, Expectations of Government and key actors	- Is there a clear vision on how the industry and market should develop? - In terms of growth - In terms of technological design - What are the expectations regarding the technological field? - Are there clear policy goals regarding this technological field? - Are these goals regarded as reliable? - Are the visions and expectations of actors involved sufficiently aligned to reduce uncertainties? - Does this (lack of) shared vision block the development of the TIS?
F5 - Market Formation - Projects installed (e.g. wind parks planned, site allocation and constructed)	- Is the current and expected future market size sufficient? - Does market size form a barrier for the development of the innovation system?
F6 - Resource Mobilization - Physical resources (infrastructure, material etc) - Human resources (skilled labor) - Financial resources (investments, venture capital, subsidies etc)	- Are there sufficient human resources? If not, does that form a barrier? - Are there sufficient financial resources? If not, does that form a barrier? - Are there expected physical resource constraints that may hamper technology diffusion? - Is the physical infrastructure developed well enough to support the diffusion of technology?
F7 - Counteract resistance to change/legitimacy creation - Length of projects from application to installation to production	- What is the average length of a project? Is there a lot of resistance towards the new technology, the set up of projects/permit procedure? - If yes, does it form a barrier?

5.3 Data analysis

For this research, the interviews with the experts were used as the main data to analyse the processes, in which the literature review was used to substantiated and/or give clarifications of the findings. For the analysis of the data obtained from the interviews, Nvivo 11 program was used. Thematic coding was used in which the themes were divided into the seven functions of the TIS, procurement (Standards and rules, routines and decision-making criteria). A constant comparative analysis was used for iterative coding. The analysis of the categories was approached with pattern matching and identification of relations between the different categories. With this process, the drivers and barriers for each of the functions could be identified.

For the analysis of the role of GPP, both the data from the literature review and the interviews was used to evaluate the influence and process of procurement by both Dutch municipalities and housing corporation in the Dutch construction sector. The indicators for each of the PP aspects and the system functions were used to identify barriers hampering the implementation of 'Green' in PP for market formation of sustainable innovations. By combining both the concepts, thus the link of GPP with the TIS framework as part of market formation, a broader view was given on the steps necessary to accelerate the technological transition in the market of an existing socio-technical regime.

5.4 Ethical issues

During this study, the interviewee were asked for approval for which the form 'informed consent' was used (Appendix II). Furthermore, permission was asked for recording the interview before the interview starts. The data used from the experts were referred to anonymously and in an aggregated way in the final report. Additionally, the data obtained is demonstrated in the form of quotes. As all interviews were conducted in Dutch, paraphrasing was conducted whereby translation worded as closely as possible with attention to prevent 'lost in translation'. Confidential documents and data were stored and used responsibly according to General Data Protection Regulation (GDPR) [3]. All documents or data shared during the research were in agreement with both supervisors.

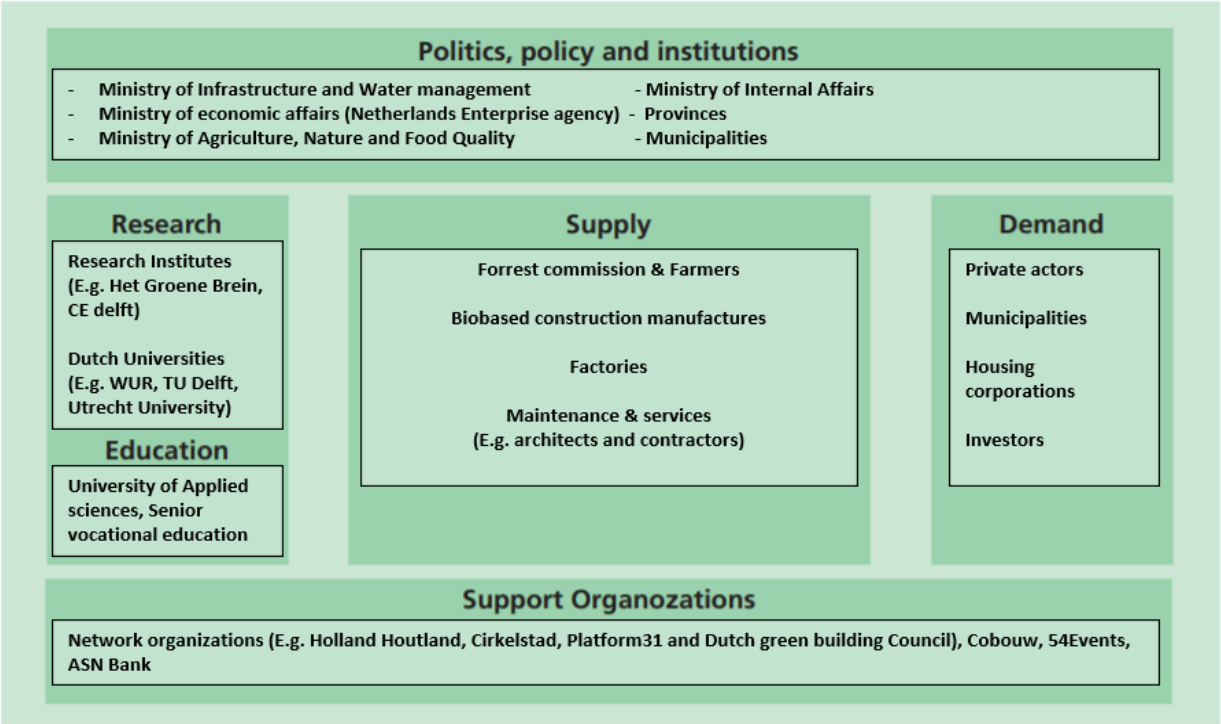
[3] https://www.uu.nl/en/organisation/privacy-statement-utrecht-university

6. Results

6.1 Technological Innovation system

The TIS has been analysed using the five steps of the framework. This paragraph focuses on the analysis of the innovation structure for biobased construction materials, in which the drivers and barriers related to the current state of development are discussed. Furthermore, an in-depth analysis is given on the role of public procurement as a tool for the demand side for the biobased construction materials.

Figure 4: The innovation system of biobased construction materials in the Dutch construction sector.



The innovation structure includes the different important actors stimulating the transition towards a sustainable construction and implementing biobased construction materials in the socio-technological system. Figure 4 depicts the actors of this system, which are based on the report of Agenda Stad (2020). The innovation structure of these materials does not include many different actors compared to the current system. The main actors which stimulate the transition of biobased construction materials are both supply and demand followed by policies and institutions.

Supply for the biobased construction materials can be divided in different categories. The actors related to the supply of resources and materials needed for this innovation form the main difference compared to the current system. In the innovation structure, (Dutch) farmers have been included as this actor can be part of the supply for resources to build the biobased construction materials. Currently, these resources are mostly imported from other European countries, however, part of this innovation is to stimulate local production of resources. Other actors are the manufacturers of the biobased construction materials. There are different companies who have developed products for biobased construction. To provide the scale-up processes for these materials, factories are necessary.

However, the scale up of these materials largely depends on the demand side of the system. Demand for biobased construction materials can be distinguished between private or public actors. An example of private actors are investors, which scale-up can be stimulated based on the ambition

of these actors regarding biobased construction materials. Public actors can play a major role in the scale-up of biobased construction materials. It has been seen that the scale-up can be stimulated if these materials will take the upper hand within building projects for residential areas. The main (semi)-public actors involved in these projects are municipalities and housing corporations, which are therefore the main actors which have been further analysed in this study. The municipality play a role in the allocation of the build of houses and industrial areas (Michielsen et al., 2019).

Furthermore, municipalities have land policies. The land policy functions as a framework for regional development. Housing corporations are the actors who build the houses, besides the private investors. However, this largely depends on the inclusion of social housing in the zoning plan of the municipality.

Another important actor in the innovation system is the Dutch government, Rijksoverheid. A key element of the socio-technological system are sectoral policies. The Dutch government plays a role in the standards and rules regarding biobased construction materials, which for both supply and demand are essential to stimulate this innovation. Provinces of the Netherlands provides spatial planning for regional level. The province decides the maximum houses the municipalities are allowed to build (Michielsen et al., 2019)

Other actors of the innovation system are research and education and support organisations. The innovation includes new techniques and knowledge through the whole chain of a building process which is provided by research and education. Furthermore, the innovation of biobased construction materials has been supported by different support organisations, which activities stimulate the transition of biobased construction materials.

6.2 Phase of development

It has been seen that the technology has been more integrated via the smaller projects, as there has been different examples of commercial applications of biobased constructions and therefore is more related to the take-off phase. These projects includes both individual projects based on the ambition of occupants to choose to build a biobased house or projects for utility buildings (e.g schools and hotels).

This research has been focussing on the biobased construction materials via the public sector, in which the public actors play a major role. With both the literature review and interviews, is has been seen that wood based materials contribute for 2% and biobased for 0,1% in the Dutch market (NIBE, 2019). The main analysis for this research has therefore been focused on the development phase, which includes the performance of all functions (figure 5).

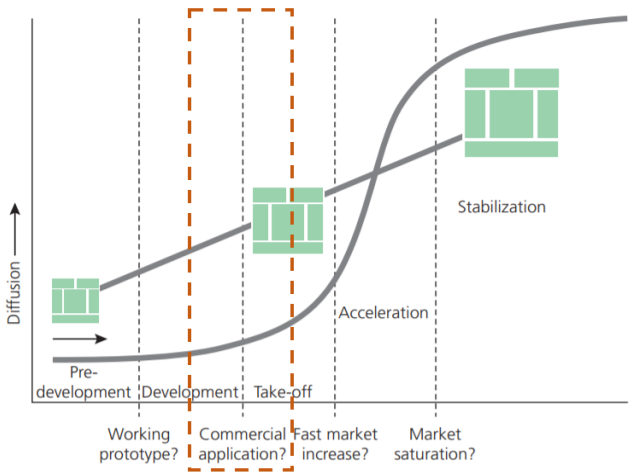


Figure 5: The stage of development of biobased construction materials.

6.3 Function fulfilment

This chapter evaluates the current events within each of the function in which for each function an analysis has been given regarding the performance in the innovation system (figure 6). The function market formation has been discussed as last in which the in depth analysis on the role of public procurement to stimulate market formation for this technology has been given.

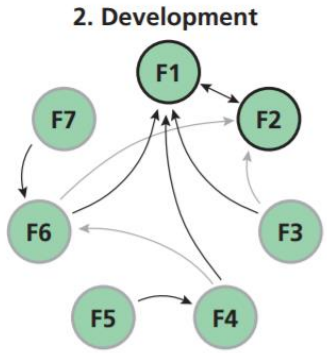


Figure 6: Function interactions of the development phase.

6.3.1 Entrepreneurial activities (Function F1)

As beforementioned it has been observed that there are different entrepreneurial activities implementing biobased construction materials. An overview of different entrepreneurs in the field for biobased construction materials has been published by Holland Houtland (2021). This gives an illustration of the activities conducted regarding biobased construction materials and the important actors essential for this innovation. For the development of biobased construction materials in the Netherlands, expert 6 stated that *"It is not at all that we cannot do it or we do not have the experience with it. Actually, countries from Europe come to us to get acquainted with the latest innovations regarding wood applications. [..]. Thus, a lot is being developed here"* (Personal communication, March 9, 2021).

Pilot projects are important to gain acceptance for the actors of the innovation system and to gather evidence on the benefits of biobased building (Expert 2, Personal communication, February 16, 2021; Expert 8, Personal communication, February 10, 2021). In addition, the use of biobased construction materials also asks for a change in the mindset and expectations of the future occupants (Expert 1, Personal communication, February 1, 2021).

However, expert 5 pointed out that *"in recent years there were a lot of good pilots, [..] but you often hear that it stops there, so scaling up pilots failed "* (Personal communication, February 15 , 2021). This barrier has been further confirmed by expert 4, *"The fact is that the experiments, pilots and living labs are often not translated into wide application of insights from those experiments within the organisation and projects"* (Personal communication, February 8, 2021). The entrepreneurial activities are currently increasing, however the transition is hampered by the fact *"[..] that what is learned from pilot projects is not translated into new policies and strategies, and that is where it goes wrong"* (Expert 2, Personal communication, February 16 , 2021).

Function analysis

This function is the main function which needs to be fulfilled in this phase of development. However, the data have shown that this function has not yet been fulfilled as focus on large scale production is limited. The insights obtained from these projects is not translated into a clear vision and strategy to stimulate the developments of the biobased materials. As illustrated in figure 6, this function performance depends on the fulfilment of the other functions in the system, which will be discussed in the following paragraphs.

6.3.2 Knowledge development (Function F2)

The presence of entrepreneurial activities demonstrates that knowledge development on building techniques of these materials has been increasing. Expert 10 stated that the focus for the pilot project is to gain knowledge on both building techniques and living experience of occupants (Personal communication, May 12, 2021) Therefore occupants will be included in the pilot project in the form of 'trial living'. The same has also been mentioned in the interview with expert 14, who is involved in the plans for a new pilot project.

"[..]For the utilization phase, we have to repeatedly analyse it and extract information. [..] We see this as an experiment trying to obtain as much information as possible, and explain this to the organisation as well [..]" (Personal communication, May 11, 2021)

However, according to the research of Studio Marco Vermeulen (2020), The Netherlands still depends on neighbouring countries regarding knowledge development on building methods and techniques, whereby it has been stated that for scaling up these materials and to build an industry, knowledge development on these aspects in the Netherlands itself is essential (Studio Marco Vermeulen, 2020).

Furthermore, it has been seen that different reports have been published regarding the opportunities in the Netherlands for the technology of biobased construction materials, which shows that the interest in these materials has been increasing. In table 5, examples of different organisations are listed which have focused their research on biobased construction materials.

This concerns publications of influential and important actors in the sector and the innovation system, which includes governmental organisations, research institutes & universities and trade associations.

Table 5: Examples of published reports by important actors in the innovation system.

Organisation	Publications	Reference
The Dutch Government: Ministry of Internal Affairs & Studio Marco Vermeulen	*Room for Biobased Building - Strategic Exploration*	Studio Marco Vermeulen (2020).
NIBE	*RVO: Potential of biobased materials in construction* *Internal CO2 pricing - As an instrument in area development*	van der Velde & van Leeuwen (2019) Van Leeuwen (2020)
TNO	*Exploring the potential of temporary CO2 storage in timber construction*	Keijzer et al. (2021)
Wageningen University	*Catalogue biobased building materials : green building*	van Dam & van den Oever (2019)
CE Delft	*Knowledge memorandum on biobased construction*	CE Delft (2021)
Circular construction economy	*Transition Agenda Circular Construction Economy*	Rijksoverheid (2018b)
Dutch Green Building Council	*Knowledge session on biobased construction*	DGBC (2020)

However, it has been observed that the overall knowledge is insufficient to stimulate the transition of biobased construction materials. When being asked on the sufficient knowledge on biobased construction materials, expert 4 emphasized:

"*No, with biobased materials, 'what we do not know, we fear'. In addition, many standards in construction are based on materials as concrete and steel. The application of biobased materials seems to have to be reinvented again. 100 years ago, almost everything was still biobased"* (Personal communication, February 8, 2021).

Function Analysis

The function knowledge development is interlinked with the function entrepreneurial activities in which both form the important functions of the development phase. The results have shown that the presence of pilot projects improves the performance of the function knowledge development, in which the type of knowledge required for this technology is increasing (E.g. living experience of occupants). Additionally, the presence of publications and reports indicate increasing developments in knowledge within different stakeholder groups of the innovation system. Though experts have stated that knowledge on biobased construction materials is still present to a limited extent which therefore shows that this function has not been sufficiently fulfilled.

6.3.3 Knowledge exchange (Function F3)

As it has been observed that knowledge development on biobased construction materials has been increasing, there have been events which give which enable the actors in the innovation system to obtain this knowledge. An example given by expert 9 is a platform which is being developed, which aims to include projects regarding biobased materials, and therefore improve knowledge exchange to different levels of government. Furthermore, it has been observed that the number of workshops, webinars and manuals on biobased construction materials is beginning to increase.

Nevertheless, expert 1 emphasized that *"actually what is essential and what is almost completely lacking, [..], is education, courses and workshops. Begin with the teachers"* (Personal communication, February 1, 2021). Which is substantiated by expert 9*, "And that must also be implemented in the entire chain, so it should be introduced into the training of architects and during the design phases*" (Personal communication, February 10, 2021). This has been evaluated in the research by Studio Marco Vermeulen (2020), which describes that there have been examples of initiatives in the Netherlands to include biobased construction materials in educational programmes. This includes the Centre of Expertise Biobased Economy of Avans and HZ University of applied sciences and department of Biobased Structures and Materials of TU Delft. However, this shows a minimum of educational programmes whereby the main focus in education programs is mainly on conventional building techniques.

Other experts have stated that a barrier has been formed regarding the knowledge on biobased construction materials in the demand side of the innovation system.

"[..] Governments focus on the process, how to get from A to B, which steps to go through, and in doing so forgetting the content and knowledge required [..]. Whereby the expert further emphasized that "*The knowledge is missing, the content is missing, the conscience is lacking in those organisations and that is why they often do not ask themselves what is necessary in this process to do the right things"*
(Expert 2, Personal communication, February 16, 2021)

This lack of knowledge exchange has also been observed by expert 15,

"They all do a pilot project, whereby knowledge obtained is not exchanged with other corporations. Everybody encounters exactly the same 'teething troubles' as the other corporations" (Personal communication, April 14 , 2021)

The lack of knowledge exchange in the innovation structure can affect clarity between market actors and demand. One expert observed that there have been misconceptions regarding the improvement of the environmental footprint in the construction sector, in which the main focus is related to building houses in a short amount of time, in which sustainability is included to a limited extent and seen as barrier in the building process (Expert 7, Personal communication, March 26, 2021).

The lack of clarity is further explained by expert 21, who stated that for smaller organizations, circularity can be seen as complex, in which a strict definition is lacking (Personal communication, March 23, 2021; Barendregt et al., 2021). The complexity of the definition has also been seen for biobased materials, especially for the plant-based materials*, "[..] what has been noticed is that, wood is tangible, and biobased, yes what is it actually?"* (Expert 20, Personal communication, March 23, 2021) Therefore, it has been observed that lack of clarity on the definition can form a barrier for both the supply and demand side in the system for the scale-up of biobased construction materials.

Additionally, it has been stated by different experts that the knowledge on biobased construction materials is missing by (potential) occupants, which can cause misconceptions regarding the appearance of buildings and the living comfort (Expert 1, Personal communication, February, 2021; Expert 16, Personal communication, April 14 , 2021).

Therefore, expert 14 explained that knowledge exchange regarding the occupants has been included in their strategy for a new project. *"[..] To provide realistic expectations [..] we try to make it as clear as possible at the beginning of what it means to live in such a wooden house."* (Personal communication, May 11, 2021). This can help the occupants to adapt their mindset regarding these buildings and improve their experiences when living in a biobased house.

Function analysis

Based on the indicators given in table 4, lack of knowledge exchange of the technology is shown to be limited between science and industry and industry and users. The industry follows a traditional mindset, and therefore, conventional materials prevail in the sector.

Generally, the lack of knowledge within municipalities and housing corporations forms a barrier in the innovation system, as they are the actors who play a role in the in the formation of building projects. Due to the lack of knowledge exchange for both occupants and the public actors, there are uncertainties and misconceptions (e.g. fire safety) regarding these materials, which cause risk-adverse behaviour. These materials are yet not preferred and therefore hamper the performance of function F1.

In addition, there are currently limited educational programmes available which focus on biobased construction methods and buildings techniques, which is crucial for the future developments of these materials.

6.3.4 Guidance of the search (Function F4)

It has been seen that ambitious climate goals have been established by the Dutch government, in which the main vision is to have a 100% circular economy by 2050. Therefore, as evaluated by expert 4, there are *"[..] Two major transitions going on, the energy transition and the transition to a circular economy. The use of bio-based raw materials is emphatically part of the circular transition"* (Personal communication, February 8, 2021)

However, It has been seen that the formation of a clear vision on biobased materials is lacking, because there is much variety between the different governmental levels in the Netherlands (Government of the Netherland, provinces and municipalities). Every level of government formulates its own policies regarding its climate objectives. Expert 4 explained that the effectiveness of these policies will only show if their policies regarding circularity and biobased materials are ambitious enough to give guidance, whereby otherwise there is no incentive for change (Personal communication, February 8, 2021). Additionally, according to the research by Beumer et al. (2021), there are uncertainties regarding the definition of these objectives per sector or material flow.

Therefore, as explained by expert 2, governments should *"[..] connect that ambition, statement or vision to strategy and policies, which happens to a limited extent. So there are a lot of governments that state, 'we have to build circularly', but there is not a single internal client[..], who declares to do this project as circularly as possible"* (Personal communication, February 16, 2021).

Furthermore, it has been seen that the sectorial policies in place are conflicting with the biobased construction materials. The main obstacle given for biobased construction materials in the interviews relates to the national policies of the construction sector. These policies are currently not in favour of biobased construction materials, which forms one of the main barriers for this transition. As emphasized by expert 18 *"[..] If you are talking about governments, [..] then you really have to do something with MPGs, and biobased materials are not really an issue there yet. That is not a topic in the regulations at the moment"* (Personal communication, April 20, 2021).

It has been further explained by expert 2 that the current calculations regarding biobased materials include burning as the end-of-life cycle instead of the reuse of the product (Personal communication, February 16, 2021). This gives different outcomes whereby the environmental impact seems to be worse than when the calculations include reuse and CO2-storage compared to concrete and steel. Additionally, the environmental data base, these calculations are based on, has not included all biobased construction materials yet. The processes needed for the calculations of biobased construction materials are expensive, as these materials are not standardised. This results in continuous calculations being necessary, which the market (innovative companies) is not able to pay for (CE Delft, 2021). In the interviews this policy has been mentioned as one of the major barriers, stating that this causes no fair level playing field in the sector for these materials. Adapting this policy and including biobased materials is a time-costly process (Expert 1, Personal communication, February 1, 2021).

Despite unfavourable policies, examples have been given in the interviews of events which demonstrate the increase of implementing biobased construction materials. An important document published has been the transition agenda of the circular construction economy (Rijksoverheid., 2018b), which has been used as guidance for the short and long term. The main goal of this agenda is defined as:

"The Transition Agenda [..] focuses on moving the building column, consisting of clients, developers, architects, prescribers, contractors and suppliers towards a sustainable and therefore circular construction economy" (Rijksoverheid, 2018b, p.11). In the transition agenda, it has been stated that this includes the incentive for the use of biobased construction materials.

Another example given is 'the City Deal Conceptual and Circular Construction', which has been seen as an important tool to give guidance for this transition (Agenda stad, 2021). The city deal has been signed by many different ambitious stakeholders who embrace the need for a sustainable construction sector. These stakeholders include both private and (semi)-public actors, knowledge institutes and network organisations. These actors strive for the formulation of a shared ambition for societal challenges, agglomeration forces by working together, involvement of both private and

public actors, being innovative and focusing on breakthroughs and being (inter) nationally appealing (Agenda stad, 2021). An important focus in the city deal is the structural use of biobased construction materials in future building projects (Agenda stad, 2021). This is emphasized by expert 2, who plays a role in this city deal, *"The ambition of the city deal is that by 2050 at least 50% of all construction flows will be bio-based, therefore 50% of the construction volumes needs to be bio-based"* (Personal communication, February 16, 2021).

Is has been observed that in many cases biobased and circular economy are viewed thematically within public organisations, which have their own policy officers. However as evaluated by expert 9 and expert 7, it should be integrated in the whole organisation (Personal communication, February 10, 2021, Personal communication, March 26, 2021).

In both the city deal and the organization of expert 9, biobased materials have been linked to the Sustainable Development Goals (SDGs), as this framework is internationally acknowledged and used in the international sustainability agenda (Personal communication, February 10, 2021). Using the SDGs supports the vision of biobased materials in broader sense, as it illustrates which climate objectives biobased materials can contribute to. This includes the SDGs.

3. Good Health, 8. Good Jobs and Economic Growth, 9. Innovation and Infrastructure, 11 Sustainable Cities and Communities, 12. Responsible Consumption, 13. Climate Action and 15. Life on Land (figure 7) (Agenda stad, 2021).

Figure 7: The Sustainable development goals biobased construction materials have been linked with (United Nations, n.d.).

Lastly, the Metropole Region Amsterdam (MRA) has published the Green Deal for timber construction. This has been signed by different actors in this region. In this green deal, objectives have been set to provide a minimum of 20% of wood-based construction of the total housing production per year, starting in 2025 (Metropool regio Amsterdam & Amsterdam Economic Board, 2020). Expert 10 works for a municipality involved in the MRA-Green Deal, which is the frontrunner in the implementation of biobased construction. This has been highlighted in BOX-I.

Function analysis

It has been observed that overall, this function negatively influences the transition, whereby the institutional component forms the main barrier for the system. Guidance is essential in the mechanisms of learning (functions 2 and 3) (Hekkert et al., 2007). Findings show that a clear objective has been set for circular construction. However, visions regarding biobased construction materials are fragmented among different governmental levels. This results in uncertainties within the development of the industry and the market, where investments for this technology are not yet forthcoming and further activities are hampered. In addition, the standards and regulations for the construction sector are mainly focused on energy performance, in which CO2 performance is limited. The MPG tool which is used for different policies in the sector for material impact calculations, is currently not in favour of biobased construction materials. These inaccurate calculations result in a missing fair level playing field for the technology, hampering developments in the entrepreneurial activities.

BOX-I: Frontrunner of Metropole region- Amsterdam – Green Deal Wood-based buildings

[..] I was asked to take on the project management to start an area development, where we would like to transform agricultural land and a part of the Staatsbosbeheer area into housing. The municipality owns quite a bit of land there. For the first step we wrote a storyline, that could be presented as starting point to the council. In 2019, I watched a 'tegenlicht' documentary and noticed new development-ideas featured in the documentary. If we do not act as a government to help this idea grow, it will be difficult to speed up in the use of (more) wood in housing. And we have the opportunity because we can use our land to give criteria for the spatial development. Therefore, together with project developers and Staatsbosbeheer the storyline was written. And I think this vision struck the right chord in trying to integrate the transition from rural areas to urbanization in a multi-purpose approach: The aim for this development – next to creating a residential area – is to eventually become an socio-economic driver for further strengthening society in education, innovation, economics and strengthening the position of natural reserves (of Staatsbosbeheer)"*

Wood-based construction has been the leading vision within the area development of the municipality. The expert stated that this vision has been used to stimulate and inspire other important actors involved in the aera development, appealing to as many actors as possible. To focus on a broader view instead of focusing on building traditional residential areas, this can improve the value of nature, education, the economic profile and future perspectives of labour markets in the region. In addition, local production and building companies have been attracted. Therefore this storyline covers the different needs of the board of the municipality (Personal communication, May 12, 2021).

As the frontrunner of the MRA-Green deal, the municipality has started focusing on, *"What is needed now? So on the one hand what is needed in the field of education? But on the other, in what way would a construction company be prepared to make such a transition? And how can it be ensured that not only new students are educated, but also the current construction workers are retrained. And, eventually be willing to move from the workplace on location to production of prefabrication of houses, which can give better circumstances regarding weather conditions and travel time. Therefore, it can be profitable in many more ways than just the (benefits of the) product itself. And that is something we have submitted".*

And that is something we have submitted".

- Expert 10, Personal communication, May 12, 2021

6.3.5 Resource mobilization (Function F6)

6.3.5.1 Financial resources

The system for biobased construction materials includes different material and immaterial resources. The most frequently mentioned barrier in the interviews has been related to the financial resources of the actors involved in the scale-up processes. As mentioned before, biobased construction materials are in the niche phase of the market and therefore these materials are more expensive compared to conventional materials.

According to the research by van Dam & van den Oever (2019), the costs of the use of biobased construction materials can increase by an average of 10%. These extra building costs are mentioned multiple times as a barrier by the experts. As pointed out by expert 13: *"So we still try to motivate our colleagues to look differently when designing residential areas where homes are to be built, [..], but in practice you see that that financial arguments plays a very big part"* (Personal communication, February 24 , 2021). This barrier is mainly seen for the demand side of the innovation system as these actors pay the extra costs and therefore it has been seen that conventional materials take preference when this lowers the building costs. Subsequently, the price of a building project has been an important aspect for housing corporations. As further stated by expert 14, *"We can rent out, but [..] we are limited by the fact that we cannot increase the rent proportionally with the costs"* (Personal communication, May 11, 2021). This has been emphasized by expert 1 (Personal communication, February 1, 2021), who pointed out that choosing conventional building materials instead of biobased construction materials will not pose a risk for corporations. In addition, housing corporations have to pay a landlord levy to the Dutch government, expert 14 has stated the following about the landlord levy: *"If a national government could lower that, then that we would have spending room [..]. At the moment, the lowest possible investment costs are the priority"* (Personal communication, May 11 , 2021).

Additionally, research has been conducted on the financial resources of housing corporations. It has been concluded in the research by Ministerie van Binnenlandse Zaken en Koninkrijksrelaties et al. (2020), that the current financial resources for building, managing and making affordable social rental housing more sustainably, will not be sufficient in the medium term. Halving the landlord levies provides housing corporations with the opportunity to invest a 20 billion in the medium term (Box-II) (Koopmans & Jongeling, 2020).

Box- II: SEO – Effects of lowering landlord levy

The investment of 20 billion euros by housing corporations in sustainability of houses, will provide 15,000 years of employment for the Dutch economy until 2025. This will increase GDP by a value of 1.4 billion euros. For the long term until 2035, this includes 2.2 billion of the GDP and 16000 years of employment, more than half of which are in the construction sector (Koopmans & Jongeling, 2020).

According to the research by Verberne et al. (2021), the current financial models used for building projects are not in line with circular construction. As explained by expert 19, *"Housing corporations must have the funds to be able to set up such projects"* and therefore the focus is lacking on the total costs of ownership (Personal communication, April 19, 2021). In addition to this, expert 3 stated that there are separate budgets for the phases of building projects (Personal communication, February 11, 2021). This currently hampers the investment in other materials in the building phase (Verberne et al., 2021). Therefore, the research by Verberne et al. (2021), proposed that the financial resources can be improved by combining the budgets, as building a circular/biobased house involves a different division of the costs, whereby a total building budget can be formed. This has also been substantiated by expert 12, that focusing on the 'project budget', in which trade-offs between (traditional) requirements within the project can reduce the total costs (Personal communication, May 25, 2021).

Lastly, expert 13 has given the example of possible subsidies for companies in the region of the municipality. These subsidies focus on small entrepreneurs wish to scale-up their innovation (Personal communication, February 24, 2021). Recently, the Dutch government has introduced a subsidy for entrepreneurs to invest in environmental friendly techniques. This is the environmental investment deduction subsidy (milieu-investeringsaftrek – MIA). This provides opportunities for investment in biobased construction materials (Circulaire bouweconomie, 2020).

6.3.5.2 Physical resources

The current construction infrastructure is traditional and based on conventional materials. The biobased construction industry in the Netherlands is therefore small and depends on other countries in Europe (e.g. Scandinavia and Germany) for its raw materials (Expert 19, Personal communication, April 19, 2021). It has been observed that it is important to invest in the local production of wood and plant materials in order to be able to supply the market with local raw materials in the future. The role of farmers in the scale-up of biobased construction materials has therefore been evaluated in the interviews by different experts. *"I think that farmers can play a very important role in making land available for growing biobased materials, which puts them in a better position, but also enables them to make huge profits in terms of nitrogen"* (Expert 6, Personal communication, March 9, 2021).

Additionally, the Dutch government has introduced the 'Forest strategy' in which objectives are given to enlarge the forests in the Netherlands (Rijksoverheid, 2020). This has been emphasized by expert 6, stating that *"Providing raw materials are essential for biobased buildings, which requires us to treat our forests respectfully, since we cannot manage with the forests we presently have [..] It is also one of the ambitions of the province to significantly increase the forest areas* (Personal communication, March 9, 2021). Therefore, as described by expert 10, both local farmers and Staatsbosbeheer have been included in their strategy for the area development projects as described in Box-I, in which the possibilities for future production and supply of wood have been integrated (Personal communication, May 12, 2021).

Another limiting factor in the scale-up of biobased construction materials is the lack of factories. According to expert 20, factories in the Netherlands for biobased construction has been increasing (Personal communication, April 22, 2021). However, these factories depend on the demand for these materials, which is currently low (Personal communication, April 19, 2021). This hampers these production processes in scaling-up biobased construction materials. According to expert 20, factories will become profitable when they can run at more than 80% productivity, and therefore can have a continuous process (Personal communication, April 22, 2021).

6.3.5.3 Human Resources

As mentioned in function F3, the need for education has been the result of the limited skilled labour regarding the building techniques and methods of these materials. To stimulate the transition, human capacity with sufficient knowledge on biobased building techniques is crucial to build a good reputation for this innovation. Faulty construction with these materials can damage the reputation of whereby resistance from consumers may increase. This has been emphasized by expert 1 (Personal communication, February 1, 2021):

"[..] The greatest danger that will now arise is that we will immediately start moving towards biobased construction. Traditional builders suddenly start building wooden houses. That can affect the reputation of wood. [..]. Thus, it is very important to use skilled people if we are going to continue making that transition".

Function analysis

The findings show that function F6 is not sufficiently fulfilled and therefore forms a barrier in the transition. The performance of this functions relates to the resources needed to improve knowledge development and testing of new technologies (Hekkert et al., 2007). For all indicators given for this function, negative events are demonstrated which cause the function to negatively influence the entrepreneurial activities.

The financial resources are currently limited in this transition. The cost of this technology ensure that conventional materials are preferred to biobased construction materials, which are lower in costs due to optimized processes. The findings have shown that there are limited financial resources (e.g. subsidies) available yet which stimulate the technology. The insufficient financial resources form a barrier for entrepreneurs in the development of the technology. This has also been seen in the physical infrastructure, where the infrastructure of the construction is conventional, whereby the number of factories for biobased construction materials is limited. The function analysis showed that this is the result of an unbalanced supply and demand. Currently, factories are not yet able to operate profitably due to the lack of demand for these materials. The lack of these industrial actors can hamper the focus on future scaled up production of biobased construction materials (F1). An additional barrier which was also seen in the function F3 is the lack of skilled labour, which is a crucial component for this transition. This relates to different actors in the in the innovation system (e.g. builders, architects, project developers). It is important for this to develop with the scale up of the technology, which now generally lacks the professionals who can build with these materials.

6.3.6 Resistance to change/ Increase legitimacy (Function F7)

The transition towards biobased materials in the Dutch construction sector as explained by expert 20, *"It is a displacement market, [..] and that makes it even more difficult. Other production methods have to disappear into the background"* (Personal communication, April 22, 2021). This has been elaborated on by expert 3 as "*There is going to be resistance because people are going to lose their jobs if a concrete factory in place X has to close [..]. And if the resistance starts to arise from maintaining employment, we can think about that, because we already know that it will be an issue in five to ten years"* (Personal communication, February 11, 2021)

However, the current construction sector has major power regarding the market. As further evaluated by expert 3 *"[..] the great risk is that the existing interests are much more strongly represented than the innovative interests"* (Personal communication, February 11, 2021). This has also been highlighted by expert 1 (Personal communication, February 1, 2021), who made the comparison with the other industries in the Netherlands, *"[..] that it has always been lacking with construction. [..] Interests are much greater compared to other industries[..]"*.

It has been observed that resistance has been further caused by the misconceptions on these materials. Different experts have explained that the main uncertainties regarding quality, (fire)safety and appearance cause the main resistance for potential occupants and constitute a risk for the public actors. An example has been given by expert 1 (Personal communication, February 1, 2021):

"[..] I work together with a builder wo makes timber frame construction, however he sticks stone strips against it. [..] So that it does indeed look like stone. It is a missed opportunity not to do it in a different way, but people would like to have a stone house. [..] Therefore, a change must also take place among consumers, that biobased is just as good on the outside as a stone house".

Nevertheless, there have been examples given by the experts in which legitimacy for biobased construction materials has been increasing. Expert 13, working in a municipality, mentioned that biobased materials have been stimulated in which a paragraph on biobased materials has been proposed for their procurement policies. This increases the legitimacy for choosing biobased construction materials (Personal communication, February 24, 2021). Both expert 9 and expert 16 also emphasized that their internal policies are focused on biobased materials (Expert 9, Personal

communication, February 10 , 2021; Expert 16, Personal communication, April 14 , 2021). However, it has been observed that this has been based on the ambition of the specific actors. Both the literature review and the experts have evaluated that the legitimacy for these materials has not been formed in national policies, which has been seen as a crucial element to scale-up these processes (Beumer et al., 2021).

Function analysis

The resistance observed regarding this technology has been shown to be the results of the limited knowledge and legitimacy regarding these materials, which causes uncertainties. This can influence the resources needed provided by the public actors (function F6) for instance regarding the skilled labour needed as resistance has observed by traditional builders. It has been seen that this function therefore shows weakly performance, which can be linked to the fulfilment of others. This barrier is not the main barrier in this phase of development in which the resistance observed can be counteracted when performance of the other functions is improved.

6.3.7 Market formation & Green public procurement (Function F5)

Both the literature review and the interviews have shown that there has not yet a scaled-up market for biobased construction materials in the Netherlands (Rijksoverheid, 2018b). As emphasized by Expert 6, *"Because a part of the market failure is missing demand, therefore you should do something in terms of demand articulation"* (Personal communication, March 9, 2021).

According to Metabolic (n.d.), the procurement of Dutch governments contributes for 18% to the climate footprint. Therefore, it has been seen that the Dutch government has set different objectives to stimulate public procurement and improve implementation of sustainable innovations in the Dutch market. An action plan has been published by the Dutch government which describes the objectives for stimulating GPP in the Netherlands for the years 2021-2025 (Ministerie van Infrastructuur en Waterstaat, 2021b). However, this reports states that GPP shows still limited effect on scaling up sustainable innovations in the Dutch market.

Therefore, to give an analysis on the role of public procurement in the scale-up of these materials, green public procurement as a demand stimulating tool has been integrated in this function. This has been analysed based on the three categories given for this policy tool (Standards and rules, routines and decision-making criteria).

6.3.7.1 Standards and rules

Both standards and rules and routines are formed based on the processes in the past, which have formed the current construction regime.

According to Netherlands Enterprise Agency (Rijksdienst van Ondernemend Nederland, n.d.), there are different laws and rules given for the construction sector related to environmental impact, which focused on both energy and materials aspects. The main laws described for new construction buildings are shown in table 6.

Table 6: The main laws for new building projects in the Netherlands (Rijksdienst van Ondernemend Nederland, n.d.).

Main laws
Building regulation (Bouwbesluit 2012)
Energy Performance of Buildings Directive (EPBD-III)
Energy performance - BENG
Energy registration and monitoring system
Environmental performance of Buildings (MPG)

It has been seen that an important national policy in the Dutch construction sector is 'Het bouwbesluit' (building regulation), which provides specific (technical) building criteria on safety, health, usability, energy efficiency and environment. Nevertheless, according to expert 14, *"the government does not prescribe which material you should use when building your house. [..] Building regulation does not specify wood or stone"* (Personal communication, May 11 , 2021)

This law is based on the minimum criteria regarding environmental aspects (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2019). However, it has been stated by different experts that including these materials in the building regulation will give a hard instrument that developers can no longer ignore (Expert 7, Personal communication, March 26, 2021; Expert 11, Personal communication, March 18, 2021).

Furthermore, it has been observed that the main focus of the environmental standards are based on the energy transition, in which the environmental aspects of construction materials are less specified. As emphasized by expert 17, "*[..] At a certain point we all started to put a lot of effort into the energy labels, and that is very good in itself, only now the energy labels are canonized. [..] what about CO2 emissions, then those labels mean nothing at all"* (Personal communication, March 11, 2021)

The law which gives calculations for the environmental impact of construction materials is the MPG-tool (Rijksdienst voor ondernemend Nederland, 2020). Subsequently, the building regulation refers to this tool for calculating the environmental impact of construction materials.

Additionally, a new label has been introduced for the environmental performance of buildings, the 'Building Research Establishment Environmental Assessment Method' (BREEAM), making it possible for buildings to obtain an environmental certificate. This standard is in relation with the MPG, as these calculations are used for the certificate (DGBC, n.d.).

6.3.7.2 Decision-making criteria

According to PIANOo (n.d. -b), the award criteria given for the environmental aspects depends on the ambition of the public actor involved. It has been observed that ambitious criteria on environmental impact is increasing within tenders of public actors. However, the environmental criteria in building projects are yet for many cases a small percentage of the award criteria for building projects. In the research of Bouwend Nederland (2020) the award criteria of 2019 for the Dutch construction sector have been evaluated, in which results show that the environmental criteria accounted for only 15% or less. As stated by expert 4, environmental criteria will be effective if this account for 50% of the award criteria (Personal communication, February 8, 2021).

According to different experts, difficulties has been observed in formulating the environmental award criteria. In addition, there have been limited tools available yet regarding circularity and biobased to monitor and test the criteria. Expert 13 evaluated to have difficulties purchasing biobased products for which the warranty is unknown, causing resistance in the organisation due to the risk it can form (Personal communication, February 24, 2021). Substantiated by expert 3, *"Because we know and can measure more, we also want to know more. And with a new product you do not know everything, and then you choose sooner for what you do know [..]"* (Personal communication, February 11, 2021).

The Dutch government have set different activities to provide and exchange knowledge on GPP. PIANOo has been introduced to stimulate GPP in the Netherlands in which knowledge exchange is one of their main activities. Furthermore, specific Buyer groups have been introduced in which both private and public actors to provide a shared market vision to improve sustainability within specific product groups, for which one is set up for biobased construction materials (Expert 4, Personal communication, February 8, 2021; Expert 5, Personal communication, February 15, 2021; PIANOo. n.d.-a). Additionally, the interviews have shown different examples of projects in which environmental criteria have been given priority. The housing corporation expert 16 works for, is one of these examples and therefore has been evaluated in detail in box-III.

Box-III: Biobased housing corporation

The corporation has spoken out the ambition for biobased construction materials for their houses in the highest level of the organisation, in which therefore has been further integrated in the whole organisation. *"In that sustainability policy we have actually made the structural choices that we have said when we develop houses, we always do it biobased".* This housing corporation is frontrunner in implementing biobased construction materials in their policies.

"[..] Normally you do a request in the form of a competition or you ask a contractor to make a pitch and what we did is, we said at the beginning, we want biobased houses and we focus on CO2 storage in the tender. That was our goal. [..] We asked the contractor, what is the profit in terms of CO2 storage in a house the moment you realize it in biobased material? And then you can also compare against each other. And that is all we have changed. [..]. Only the partner you work with and the way you do tenders, that is what has been adapted. And we are still learning".

Expert 16, Personal communication, April 14, 2021.

Despite the increase in ambition on environmental criteria, it has been stated by different experts that, in practice it appears to the price prevailed (Expert 1, Personal communication, February 1, 2021; Expert 13, Personal communication, February 24 , 2021; Expert 4, Personal communication, February 8, 2021; Expert 20, Personal communication, April 22, 2021). According to expert 9 and expert 20, if biobased pilot projects turns out to be more expensive, this will be the first thing that will be eliminated (Expert 9, Personal communication, February 10 , 2021; Expert 20. Personal communication, April 22, 2021). Furthermore, it has been observed that the effectiveness of implementation of environmental criteria in construction processes depends on where in the process this will be included. As stated by expert 11:

"[..] They say public procurement, but you have to distinguish that the procurement process is actually only at the end of the project. However, you have a project process. And that project process must be organized in a more circular manner. [..]" (Expert 11, Personal communication, March 18, 2021)

This statement has been further substantiated by expert 8, in which it has been emphasized that the choice for biobased construction materials must be included in the beginning of the building process, which will then be integrated throughout the entire process (Personal communication, March 30, 2021). As further evaluated by expert 11, the implementation of environmental criteria later in the process can provide additional costs due to changes in the pre-procurement process (Personal communication, March 18, 2021).

However, experts have stated that generally, criteria given for building projects are based on traditional procedures. It has been observed that current procedures and specifications are of great level of detail based on the traditional methods and therefore hampers to act differently (Expert 2,

Personal communication, February 16, 2021). It has been suggested that to improve biobased materials in the construction sector, detailed criteria can be converted in boundaries conditions. As stated by expert Expert 1 (Personal communication, February 1, 2021)

"We are no longer going to prescribe that the houses to be built must be built from that type of bricks, [..], but we want a family with two parents and two children who must be able to live healthy in a certain house and that house has a maximum price. Which is a completely different way of asking"

Additionally, expert 3 explained that public actors can focus on steering on the intention of the projects, in which the example was given on a lower environmental impact. Or as shown in box-III, the focus on CO2 storage (Personal communication, February 11, 2021).

However, it has been seen that the public actors involved play a different role in setting criteria for residential areas. According to expert 16, the set of instruments for the municipality to exert influence lies with the zoning plan and land policy, in which they have an enforcement role regarding the housing corporations and private actors (Personal communication, April 14, 2021). This has also been seen in Box-I, in which criteria have been set for area development. According to the research of NIBE & van Leeuwen (2020), land policies are yet not been used to implement environmental criteria. Nevertheless, this research stated that this will be the place in which municipalities can influence the environmental impact of residential's areas and therefore not their procurement process.

Furthermore, municipality set in accordance with housing corporations performance agreements, herein also criteria regarding sustainability being implemented in building projects of the corporations. This is signed every four years by both actors. Nonetheless, as stated by expert 11, there can be differences between corporations regarding sustainability ambitions in the organisation and therefore these agreements cannot be set too high as these corporations are not able to achieve this.

6.3.7.3 Routines

The limited integration of environmental aspects in the decision-criteria can be linked to the routines within organisations. It has been evaluated by different experts that within both municipalities and housing corporations procurement processes are related to routine-based behaviour. It has been seen that GPP is not the standard process yet, in which it has been emphasized by expert 2 that everything which is currently 'standard' must be changed (Expert 2, Personal communication, February 16, 2021). As evaluated by expert 1 a standard procedure is used for the procurement of products in which sustainability aspects are limited (Expert 1, Personal communication, February 1, 2021). The ambition for sustainability has been increasing within public organisations, however, "*they often want to but are stuck in systems, habits, routines and decision-making with how we always did in the past"* (Expert 3, Personal communication, February 11, 2021)

Expert 5 pointed out that procurement for climate adaptation can be achieved more easily compared to a circular procurement process, radical changes are needed in the current system (Personal communication, February 15, 2021). This has been further evaluated by both experts 1 and Expert 17, which have explained that using biobased construction materials for residential areas require new partners in the value chain. This means that the current actors normally involved and therefore well known, are substituted. This can cause resistance and uncertainties by the actors. (Expert 1, Personal communication, February 1, 2021; Expert 17, Personal communication, March 11, 2021)

Additionally, it has been observed that the routine-based behaviour is linked to the lack of knowledge on biobased materials and a traditional mindset have shown to be the main barriers regarding the routine-based behaviour. Subsequently, it has been seen that pressure and working load is increasing for municipalities as more tasks are given by the Dutch government (Expert 11, Personal communication, March 18, 2021), as stated by expert 3, *"Municipalities therefore have an high workload and the only way they can deal with it [..] is to focus on overall strategy [..]"* (Personal

communication, February 11 , 2021), which has resulted in the lack of human capacity to broaden the internal knowledge, on for instance biobased construction materials.

Function analysis

Based on the theory of Hekkert et al. (2007), a lobby for market formation has been observed for the transition of biobased construction materials in the Netherlands, as the barriers identified cause a missing level playing field. It has been shown that changing the construction regulations is a time costly process (+/- 2 years) (F4), hence the lobby for market formation can improve guidance regarding this technology. This has also been illustrated in figure X, which demonstrates that the function market formation directly influences function F4.

The findings have shown that function F5 is currently weakly fulfilled as the current market size is not sufficient to stimulate further developments of the technology, and therefore negatively influences the innovation system. GPP has been included to analyse the effectiveness of this demand-stimulating tool in the transition of biobased construction materials. The findings have shown that the indicators given for GPP are presently not sufficiently integrated in the public processes of housing corporations. Due to the lack of policies regarding biobased construction materials and as a result limited guidance, this can also affect the effectiveness of procurement to stimulate demand (standards & rules). According to Rainville (2016), the adaptation of innovative technologies depends on the compatibility with the existing infrastructure of the sector. The current standards of the construction sector have been shown to focus on requirements which do not stimulate this technology in a correct manner. Conventional materials can achieve these requirements too which gives no extra incentive to choose biobased construction materials. This indicator negatively influences both functions F4 and F5 and therefore the functions do not reinforce each other.

Subsequently, It has been observed that the other system barriers identified affect the effectiveness of GPP. According to Hsueh et al. (2020), *"Procurement choices must meet the needs and requirements of the public organisation while also paying attention to limited operating budgets" (p. 699).* This also applies to the Dutch construction sector, in which the price criteria have been shown to be dominant in building processes and therefore form a barrier to choose biobased construction materials. This can be linked to the limited financial and human resources of the public actors (Function F6). In addition, an indicator given for GPP decision criteria is the access to information. In relation to function F3, the access to information on biobased construction materials is limited for the main public actors involved. It has been observed that there are uncertainties regarding formulating and measuring criteria for biobased construction materials. Consequently, well-known products are chosen as this forms no risk for the actors. The procurement processes of the Dutch public actors are based on routines of the current infrastructure of the construction sector. As stated by Hsueh et al. (2020), "*To ensure procurement professionals can meet their service priorities, they must rely on existing decision-making processes and structures to accomplish their work*" (P. 699). The limited possibilities to act differently within public organisations, have had the effect that the public actors are stuck in their 'traditional' routines. The system barriers and their interrelations with the categories of GPP are given in table 7.

Based on the findings is has been seen that in general, GPP has not been integrated in the current procurement process of the Dutch public actors yet, and therefore insufficiently stimulate the demand side of the innovation system. Nevertheless, the examples given in the findings have shown that focusing on the decision-criteria can provide possibilities to stimulate market formation for biobased construction materials. Changes in the tendering process have shown to be effective to stimulate biobased construction materials. The following paragraph therefore evaluates the recommendations given to overcome the barriers and diffuse the technology to the next phase.

Table 7: The function barriers identified and their interrelation with the performance of GPP.

F5.1 Green Public procurement	Interrelations of the function performance and GPP
Rules and Standards	*F4: Guidance of the search* -The technical specification given in the building regulations describes the minimum needed, and therefore there is no incentives for biobased construction materials. -The standards present are mainly focused on energy in which the focus on CO_2 is limited. -The MPG tool has been used for different standards and ecolabel(s). However, this is currently not in favour of biobased construction materials.
Decision-making criteria	*F3: Knowledge exchange* -Within both municipalities and housing corporation, generally the knowledge on circular/biobased construction is limited. This can hamper formulating environmental criteria in tenders. -There have been uncertainties and misconceptions regarding warranty, quality and monitoring possibilities for these materials. *F4: Guidance of the search* -The subject of biobased construction materials is often thematically viewed within public organisations, whereby embracement by the entire organization is limited. This influences the decision-making criteria in building processes.
Routines	*F3: Knowledge exchange* -Lack of knowledge can result in a traditional mindset and routines of the stakeholders involved *F6: Resources mobilization* -Municipalities have limited budget and human capacity in relation to the task given by the Dutch Government. Therefore, there are limited opportunities to improve their knowledge on new products. -Housing corporations have limited financial resources due to the regulations required for social houses. *F7: Resistance to change/creating legitimacy* - New partners in the value chain substitutes the current parties normally involved and therefore well known

7. Discussion

Biobased construction materials are part of technological change, and therefore the TIS framework helped to identify the barriers which need to be overcome to accelerate the transition and to form a market. To stimulate market formation for biobased construction materials, this study therefore contributes to an in-depth analysis on the demand-side of innovation system analysis and the role of public procurement as an integrating element of the TIS-framework. The integration of GPP in the TIS framework has provided the possibility to identify the barriers which cause low demand for the technology. This has been linked to the performance of the system functions. Including GPP in the framework has given insight into the development process of internal organisation of public actors. Including the PP process in the early stage of transition has given insight into the processes needed to overcome the barriers hampering the improvement of PP towards a GPP process. These parallel developments of both technology and GPP can improve the function market formation in the acceleration stage. The substitution of conventional materials for biobased construction materials implies a whole system change instead of changes in the purchase of products. Therefore, different stakeholder groups need to adapt their current processes to stimulate market formation.

The function analysis has shown that the policies for the Dutch construction sector are not in favour of biobased construction materials and will therefore not exert any pressure on the current regime to change (Geels, 2002). The focus should be on other windows of opportunities to implement biobased construction materials in the Dutch construction sector. The discussion that has arisen in this transition is which actor starts the acceleration of the technology. The uncertainties between supply and demand currently hamper the development of the technology. Biobased construction materials are available on a small scale in the Dutch market, which can result in low demand. However, due to low demand, the entrepreneurs cannot develop on a larger scale. This can mainly be seen for the factories needed, which only operate profitably when materials are requested on a large scale. An explanation is given in the research of Bleda & Chicot (2020), which describes that a possible reason for limited demand is that public actors do not have the knowledge regarding the existence and/or characteristics of the innovative solutions which can meet the objectives of public organizations. Furthermore, suppliers can be faced with uncertainties and risks due to limited trust in structural demand for the technology or limited resources to provide the products for customers' needs (Bleda & Chicot, 2020). As observed in this research, the lack of knowledge exchange and limited material and immaterial resources has formed major barriers in the transition of biobased construction materials. Therefore, events should be in place which provide easy access to the knowledge required for all actors involved, whereby public actors can provide resources to stimulate supply, which in turn can meet the demand of the innovation system.

Moreover, differences have been observed in the role of the governmental levels in the transition of biobased construction materials and therefore the effectiveness of their public procurement processes in this transition. In the case of the building process for residential areas (scale-up process), public procurement only refers to housing corporations. Dutch municipalities have a different role in building projects of residential areas in which their procurement process is not involved. For the transition of biobased construction materials, municipalities can set their environmental criteria in the form of regulations (land policies), which refer to a different demand-stimulating policy tool (Bleda & Chicot, 2020). Focusing on environmental criteria for area development which includes building of residential areas, has been seen as another possibility to implement environmental aspects in a building process. As this study has focused on the role of public procurement, it has been stated that the transition is a system change of which public procurement is part. The effectiveness of this tool therefore depends on the performance of other elements in the system in order to stimulate sustainable innovations. Further research therefore can be conducted on the effectiveness of other demand stimulating policy tools for stimulating sustainable innovations in a static socio-technological regime.

Besides public procurement, it is important that other actors in the innovation system adapt their processes to improve the performance of the whole system. Biobased construction materials in the construction sector provide the opportunity for multiple climate and societal challenges. This improves healthier living and work environments, ensures economic impulse and reduces the overall environmental impact of the sector. The scale up of biobased construction materials also provides opportunities for Dutch farmers to reduce their environmental footprint, stimulating local production. Currently, farmers are having difficulties in dealing with the nitrogen crisis and their businesses. The scale-up of biobased construction materials can create a new business case for Dutch farmers. These materials can function as their main business products. This also includes the focus on local production of wood in Dutch forests. However, these transitions are out of the scope of this research, but this system analysis is important for the future developments of biobased materials.

In addition, the climate objective given for the Dutch construction sector of 100% circularity by 2050 can be defined as a 'mission', involving different technologies. Therefore, additional research can be conducted using the framework 'Mission-Oriented Innovation System (MIS)' proposed by Hekkert et al. (2020). This framework focuses beyond technology solutions, in which for instance the analysis of behavioural and organisational change has been included (Hekkert et al., 2020). Based on the findings of this study these elements are essential for the transition towards a circular/biobased construction sector. Lastly, this research has contributed to the role of public actors in scaling up innovative technologies in a static regime. However, in addition the role of private actors can be researched for the scale-up of this technology. In the scale-up processes, both housing corporations and private actors form the demand side of the innovation system and therefore both should be included in market formation for the technology.

7.1 Limitations

A limitation is observed regarding integrating GPP in the TIS framework. The link has been made between GPP and market formation (function F5) in this framework. This only becomes relevant if the technology is already in the development phase. For technologies in the pre-development phase, integration of public procurement in the TIS framework may have limited effect as the function market formation does not play a role in this stage of development. Furthermore, inclusion of GPP in the TIS framework implies a new approach which leads to difficulties in generalizing the results. This research is a qualitative research, in which the data analysis depends on the interpretation by the researcher, for instance in prioritizing certain events compared to others. Therefore, further research can be conducted on GPP as an integrating element of the TIS, to improve the validity.

8. Conclusion

An important climate objective of the Dutch government is a 100% circular economy by the year 2050. This also accounts for the Dutch construction sector, whose traditional processes and materials have a large share in GHG emissions. Substitution of conventional materials with biobased construction materials provides the opportunity to achieve different climate objectives. Nevertheless, biobased construction materials still have a small market share in the current Dutch construction sector. To achieve the climate objectives, a market needs to emerge which stimulates the scale-up of these materials in the Netherlands.

It can be concluded that the current state of the technological transition is the development phase. Entrepreneurial activities and knowledge development are the important functions of this phase of development, however their performance is insufficient. Based on the function analysis, the supportive functions, *F3: knowledge exchange, F4: Guidance of the search and F6: resource mobilization,* currently form the main barriers.

The interest in biobased construction materials is increasing in the Dutch construction sector, however knowledge exchange is limited between important actors of the innovation system. The lack of knowledge exchange caused uncertainties for both supply and demand in the innovation system. The main barriers identified is that knowledge learned from pilot projects is not translated into a strategy for future developments. In addition, education programmes regarding the building methods and techniques are inadequate. Skilled labour is essential but is currently limited (Both function F3 and F6). To improve the performance of this function, access to information and knowledge exchange should be improved for different actors involved. A suggestion given is including biobased construction methods and techniques in educational programmes and retraining of the current employees towards this new system.

Furthermore, despite the current national policies for the Dutch construction sector are not in favour of biobased construction materials, there is also no shared vision as differences have been observed among the governmental levels in the Netherlands. This forms a barrier for further investments by entrepreneurs in these materials. To accelerate this transition, it is recommended to focus on the possibilities to stimulate market formation via housing corporations and municipalities. These actors play a role in demand creation, which has been linked to the procurement process. Based on the findings, it can be concluded that public procurement as a demand-stimulating tool does not stimulate this technology sufficiently yet. For this process too, the current standards form a barrier for public actors to choose these materials. To stimulate market formation, it has been seen that implementing the environmental criteria at the beginning of a project will enhance the effectiveness of these criteria in the building process. Furthermore, it is recommended to analyse the possibilities for adapting the decision-criteria from detailed specifications towards boundary conditions. Findings shows that If building specifications adapt towards a procedure in which the focus is related to the environmental intentions (e.g. CO2 storage), this can improve the possibilities for the entrepreneurs to invest in their businesses.

However, concerning resource mobilization, the limited financial resources hamper further investments of entrepreneur. The niche market of biobased construction materials results in higher prices of the materials compared to conventional materials. It has been seen that this forms a barrier as public actors have limited room for manoeuvre in the budget therefore in general price prevails. To overcome this barriers, financial support can be provided by the Dutch government in the form of subsidies or changes in the compulsory landlord levy. This can close the financial gap needed to invest in biobased construction materials. Other suggestions given are combining of the building budgets which provides to opportunity to increase the investment budget necessary.

To recapitulate, in order to accelerate the transition towards biobased construction materials, improvements in the function market formation and the main barriers, can give an impulse in the market for biobased construction materials and therefore reinforce the performance of the other functions of the innovation system. identified

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Appendix I – Interview Guide

Het interview wordt een semi-structured interview, dus de vragen in dit document worden als richtlijn gebruikt.

1. Welke actoren spelen een grote rol in de transitie van regulier naar bio-based constructie materialen?
2. Welke actor is belangrijk en wie doet wat en waarom?
    a. Hoe innovatief zijn op dit moment de industriën
3. Wat zijn redenen waarom er nog niet op grote schaal gebouwd wordt?

4. Is de kennis over bio-based construction materials voldoende onder bovengenoemde actoren?
5. Hoe vindt de kennis ontwikkeling plaats?
6. Wordt deze kennis voldoende uitgewisseld tussen de actoren?
7. Wordt kennisuitwisseling op dit moment gezien als een barriere om de transitie van bio-based materials te versnellen?

8. Is er een concrete visie voor hoe de markt van bio-based contructie materialen zich moet gaan vormen in het huidige systeem?
9. Zijn er duidelijke beleidsplannen om bio-based constructie materialen te implementeren in het huidige systeem? En zijn deze beleidsplannen realistisch en betrouwbaar om deze markt door te gaan voeren?

10. Hoe ziet u op dit moment de markt voor bio-based constructie materials?
    a. Is de marktomvang voor bio-based constructie materialen voldoende?
    b. Wat is de grootste barriere in het vormen van de markt?

Een onderdeel om markt formatie te stimuleren is het inkoopbeleid van overheidsinstellingen

a. Op basis van welke factoren wordt het huidige inkoopprocess bepaald?
b. Hoe wordt het begrip duurzaamheid hierin meegenomen? En wat wordt er gezien als duurzaamheid?
c. Zijn de standaarden op het gebied van de technische specificaties van een product gericht op duurzaamheid?
d. Het inkoop process verloopt vaak vanuit routines, hoe komt duurzaamheid hierin terug?
e. In hoeverre wordt op dit moment duurzaamheid meegenomen in de guninngscriteria? Indien nodig; Waarom blijkt in de praktijk dat duurzaamheid niet een priorieit heeft?
f. Kiezen belanghebbende voor duurzaamheidscriteria in het inkoop process?
g. Wie is de klant? En hoe wordt de wens van de eindgebruiker bepaald?

11. Zijn er voldoende materieel en niet-materiëlen middelen om de markt te vormen?
    a. Welk onderdeel vormt hierin de grootste barriere om de markt te vormen en/of op te schalen?
12. Is er veer veel weerstand tegen de ontwikkeling van bio-based constructie materialen?
a. In welke mate vormt deze weerstand een barrier?

Wat is er volgens u nodig om deze barriers weg te nemen?

Appendix II - Informed Consent

INFORMED CONSENT FORM for participation in:

The role of green public procurement in the transition of bio-based construction materials in The Netherlands

To be completed by the participant:

I confirm that:

- I am satisfied with the received information about the research;
- I have been given opportunity to ask questions about the research and that any questions that have been risen have been answered satisfactorily;
- I had the opportunity to think carefully about participating in the study;
- I will give an honest answer to the questions asked.

I agree that:

- the data to be collected will be obtained and stored for scientific purposes; the collected, completely anonymous, research data can be shared and re-used by scientists to answer other
- research questions;
- video and/or audio recordings may also be used for scientific purposes.

I understand that:

- I have the right to withdraw my consent to use the data;
- I have the right to see the research report afterwards.

Name of participant : _____

Signature: _____ Date, place: ___ / ___ / ____, _____

To be completed by the investigator:

I declare that I have explained the above mentioned participant what participation means and the reasons for data collection.
I guarantee the privacy of the data.

Name: _____

Date: ___ / ___ / _____(dd/mm/yyyy)

Signature:

_____