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Modernizing the Dutch Housing Industry using off-site construction

Removing adoption barriers through innovation policy

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This thesis project is the conclusion of my journey following the degree of Complex System Engineering and Management at TU Delft. At the time that I'm writing this section, the world is struggling with a pandemic that has affected if not all, a large majority of the people on the earth. The pandemic changed the way we live, interact, move, learn, work and trust. Personally, I have not escaped these struggles and the adaptation process that came along. However, these struggles have been better-navigated thanks to the support and love of the people closest to me. This short section is dedicated at these immensely good people who cared, motivated and encouraged me throughout the process of writing this thesis.

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Executive Summary

The construction industry is considered as a low-productivity industry when compared to other industries who have managed to adapt better to the technological developments of recent times. Several social and economic developments could magnify the effects of low productivity and create a systematic failure that would lead to the under-provision of infrastructure. Off-site construction is considered a solution to some of the failures of the construction industry. Even though off-site construction or variations of it have been around since the 19th century, its adoption and widespread use have only been mainstream as an efficient construction method in the period following the Second World War.

If we consider off-site construction as an innovation, we could argue that in the current construction industry off-site construction is (in most cases) an innovation new to the firm, radical, high-tech, and both process and product. If off-site is to be adopted, multiple stakeholders, practices, routines, institutions (rules) should be addressed and managed. Moreover, off-site construction also represents a service innovation, which will require the restructuring and re-design of supplier-client relationships to ensure that the mistake of pushing for off-site construction without a customer focus is not repeated in the present.

To determine why the uptake of off-site is still low in the construction industry in the Netherlands, we have developed an exploratory case study to investigate what are the adoption barriers of off-site construction in the Netherlands. This case study provided us with a better picture of why off-site adoption is still low. With this information, based on innovation diffusion and system transformation theories, we provided a list of recommendations and roles that the national and local public authorities could implement to incentivize the adoption of off-site construction products.

Systems of innovations, strategic niche management and transformation management are three approaches used by policy-makers and academics to justify the need for state intervention. Based on these three frameworks, we have compiled a list of 18 activities or functions that the innovation policy system must address to promote innovation effectively. Moreover, the literature on governance of change describes thirteen different roles that the government might assume different roles based on the failure it aims to address.

An analysis of the construction industry based on academic and grey literature shows that the construction industry has different failures that might affect the process of innovation creation, diffusion and adoption. These failures can be summarized in dependency on cycles to balance their operations, lack of IP protection for innovations in the built environment; the project nature of the construction industry; lack of leadership and; current procurement practices.

Through the use of semi-structured interviews among lead or potential user of off-site products, we have discovered fifteen demand-sided and ten supply-sided barriers in the adoption process of off-site construction. Moreover the identified barriers were divided based on the impact they have on the general construction innovativeness or if their impact relates only to the adoption of off-site construction.

Barrier that impact the general innovativeness of the construction industry and the adoption of off-site construction are: insufficient benefits v. associated risk (the chicken or egg dilemma), mismatch between investors demands and the nature of the construction industry, lack of leadership, procurement practices and changes in construction paradigms.

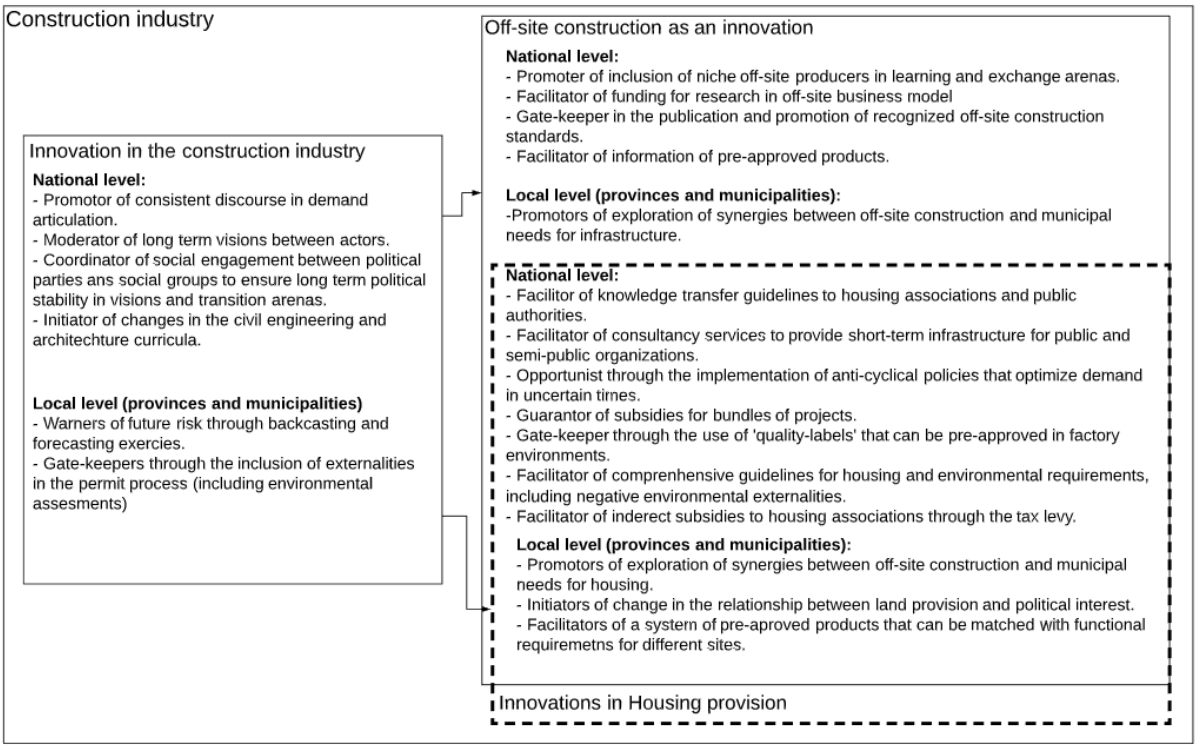
Barrier that relate to the specific challenge of adopting off-site construction are: lack of certainty about the role of stakeholders and partners, conflicting/missing regulations, uncertainty about performance, increased need for integration of stakeholders early in the process, design freeze limitations, lack of organizational infrastructure, lack of time/resources needed to integrate stakeholders early in the process, a poor or negative image of off-site construction methods, lack of flexibility and adaptability in the late project stages, higher initial cost, a higher level of complexity (throughout the process), higher risk due to the lack of information, ability of products to fit consumer expectations, increase risks of higher cost due to logistical constraints, aesthetics and product flexibility and land provision.

We provided fifteen recommendations for the central government, via its different organizations, that could help incentivize the adoption process of off-site construction products. Moreover, we have provided recommendations that should help the long term health of the construction industry and improve the possibilities to fulfil its social role. Additionally, at the Municipal level, we have provided five recommendations aimed at creating and fostering markets for off-site construction products.

The central government should act as **promoter, moderator, facilitator, coordinator of social engagement, initiator, guarantor and gate-keeper** to help incentivize the adoption and upscaling of off-site construction products. However, we highlight the importance of providing long term visions and leadership. Moreover, the government should align the long term health and stability of the construction industry with long term plans and be willing to compromise to achieve the potential of off-site construction fully.

As in the case of the central government, the local authorities could act as **promotors, moderators, facilitators, coordinators of social engagement, initiators and gate-keeper**. These are examples of actions that could help to reduce uncertainty and improve the uptake of off-site construction. We highlight the capacity of Municipalities to create markets for off-site products. On the other hand, we recognize that in their current roles, they act as inhibitors of technological change. Moreover, municipalities could play an essential and active role in the transformation of the construction industry, but they too should be willing to adapt and change.

These recommendations were classified based on the goals they address. Four national and two local government recommendations and roles address the innovativeness of the construction industry and the adoption of offsite construction. Four national and one local government recommendations were made to improve conditions that are specific to the technology. Seven national and three local government recommendations and roles were made to improve housing provision through off-site construction innovations. These recommendations are depicted in the figure below.



This thesis was conducted as the culmination of the program CoSEM at TU Delft. The main focus of the program is the design of interventions for socio-technical systems. This thesis, through a case study and innovation policy, provides a policy recommendation for the Dutch government to intervene in the socio-technical system of the construction industry. The main audience of this thesis is public decision-makers.

However, the recommendations and analysis here provided should be of interest for private actors that are interested in the adoption of off-site construction in their business practices.

The scientific relevance of this thesis lies in the innovative approach taken to analyse the problem of change in the construction industry for off-site construction adoption. The approach used in this thesis is based on the fact that off-site construction deviates greatly from traditional construction practices. Therefore, it will require a high level of coordination and joint effort. Moreover, we intend with this thesis project to create a sense of urgency about the challenges that need to be overcome to modernize the construction industry, not only through off-site construction but for other technologies as well.

The construction industry will be especially prone to the effects of the grand challenges that society faces. Therefore, this thesis aims at providing an innovative perspective on an old solution for some of the problems of the construction industry. The societal relevance of this project lies in providing a sense of urgency for multiple actors to realize that modernization is long due and that large change will require strong multi-actor cooperation and leadership.

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1 Introduction

1.1 Research problem

The provision of housing is a central objective in the agenda of governments and planning authorities (Hamid et al., 2018) and one of the primary income sources for the construction industry. However, given the nature of the construction industry, demand is not always aligned with supply and therefore, a mismatch between the societal needs and the production capacity arise. Additionally, in recent years, a stable economy with good performance has caused an increase in demand, which, combined with low capacity, resulted in soaring prices. Moreover, an increase in seasonal workers, immigration and the economic effects of the COVID-19 pandemic (CBS, 2020) might further increase the gap between the construction industry capacity to deliver infrastructure and the demand for it.

Historically, the construction industry has been slow to adapt to demand requirements, commonly subjected to slow speculative cycles that align with economic developments and in many cases end up with an overshooting of supply (De Vries and Boelhouwer, 2010). The speculative nature of the construction industry is caused by several reasons like inefficiencies in the approval system, funding constraints imposed by the government, low innovation rates and a mismatch between the demand and supply (see Figure 1). Of particular interest for this thesis is the low innovation rate. Low innovation rate causes low productivity growth, which in turn, makes the industry less productive in comparison to other industries such as manufacturing and retail (Winch, 2003, Hofman et al., 2009, Koskela and Vrijhoef, 2001).

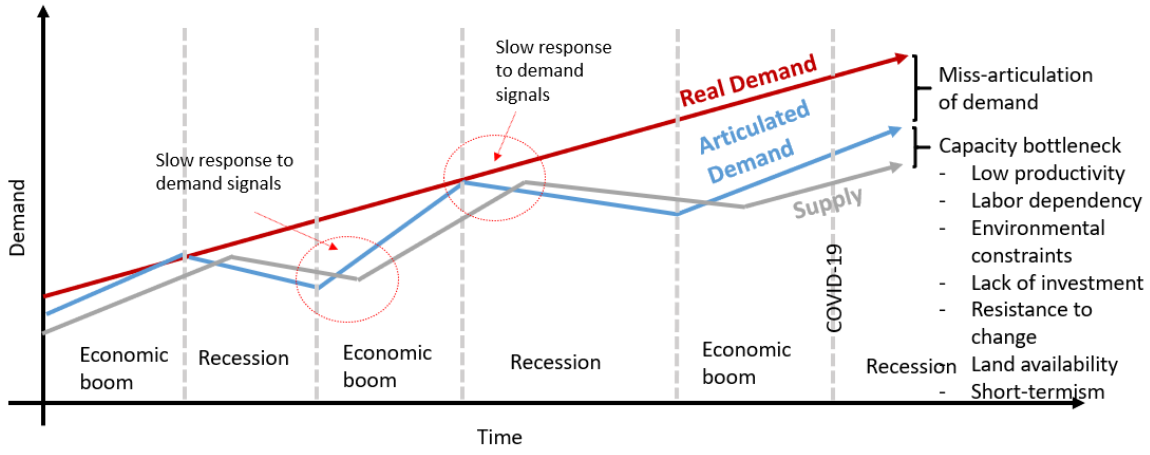


Figure 1 Response of supply to demand requirements (own figure)

An innovative solution that has become of particular interest for governments and the industry to solve the problem of low productivity growth is the use of modern construction methods (Terner Center for Housing Innovation, 2017, Farmer, 2016). One of these methods is off-site construction, which is the process of prefabricating elements off-site so they can be later assembled on-site (O'Connor et al., 2014). Off-site construction is not new, and in some countries like Japan and Sweden, it is widely used (Koebel et al., 2004). In other countries like UK, Australia, Singapore and Hong Kong governments are pushing the construction industry to adopt this technology (Burgess et al., 2018).

The Netherlands recognizes the need to build homes at a large scale in the upcoming years to cover future demand (Jongeneel, 2018). On the other hand, it is not clear if the current industry is capable of delivering the expected results, especially at affordable prices while maintaining a healthy profit margin in the industry (Burgess et al., 2018). Hence, the actors within the system have the societal challenge to

look at possible solutions to address these problems, not only to improve the economic prospects of the construction industry but also to ensure that the economic and social benefits that the industry aims to provide can be realized. The use of off-site construction technologies, in the Netherlands, is gaining traction among different actors in the construction industry including housing associations, banks, umbrella organizations, the academia and government bodies (Bujis et al., 2019, Wisse, 2020, Ministerie van Landbouw, 2019, Oorsprong, 2018, Halman et al., 2008). However, at this point, some barriers need to be bridged so that the benefits can be entirely realized (Choi et al., 2019).

Introducing new construction methods to the industry will require broad and robust cooperation and commitment from different actors in the chain of supply (O'Connor et al., 2014). The national and local government can play a role in the process of technology adoption in the construction industry, not only because it can use public policy to incentivize innovation but also because they represent the largest client to the construction industry (Halman et al., 2008, Lenderink et al., 2019a). Moreover, through the use of innovation policies, regulations and the promotion of innovations governments can act as the originator of change and play a role in shaping the market for innovations (Borrás and Edquist, 2013, Schot and Steinmueller, 2018, Mazzucato, 2016). An example of this is the position that the UK's government assumed in their push to modernize the construction industry (Burgess et al., 2018).

Moreover, because of the strong dependence on the services that the society has on products from the construction industry, the demand-driven market and the exploitation focus of the construction industry voluntary change seems unlikely (Farmer, 2016, Eriksson et al., 2014, Faber and Hoppe, 2013).

1.2 The need for research on off-site construction in Dutch construction industry

1.2.1 Identifying the knowledge gap

Off-site construction is not a new concept. Early off-site construction concepts were developed during the industrial revolution in the 1800s. In the period following WWII, there was a need for fast mass production to replace and rebuild damaged infrastructure, and some countries experimented and pushed prefabrication as an answer to this need (Jongeneel, 2018). Nevertheless, the techniques and methods used left consumers with the idea that off-site construction was of low and poor quality (Tam et al., 2015). This feeling, together with poor maintenance led the current construction methods to replace off-site construction. However, with the advancement, implementation, and use of recent technological developments in manufacturing and quality control have created new opportunities for off-site construction to challenge these old misconceptions (Davies, 2018).

Different studies have focused in understanding and showing how the construction industry would benefit from the widespread use, and adoption of off-site construction have been conducted (Blismas et al., 2010, Burke and Miller, 1998, Ferdous et al., 2019, Li et al., 2014, Lu and Korman, 2010, Nadim and Goulding Jack, 2011). However, off-site construction requires considerable changes in the way the construction industry operates. Studies on the adoption barriers of off-site construction have been conducted predominantly in the context of countries like the UK, China, Sweden, Australia and the US (Arif et al., 2012, Choi et al., 2019, Dave et al., 2017, Edquist and Zabala-Iturriagagoitia, 2015, Lu and Korman, 2010, Pan and Goodier, 2012).

Other studies have been conducted to understand the attitude and roles of different stakeholders in the adoption process of off-site construction, showing that even when the benefits and the potential of off-site construction are well understood, current practices are not geared towards the use of more prefabrication (Halman et al., 2008, Goodier et al., 2019, El-Abidi et al., 2019, O'Connor et al., 2014, Dave et al., 2017, Hamid et al., 2018). Arif et al. (2012), Choi et al. (2019) studied critical success factors for the adoption of off-site construction, however, as they point out they are usually highly dependent on geographical and institutional constraints.

In the context of the construction industry innovation and change has been studied in different perspectives, for example, supply chain (Koolwijk et al., 2018, Pan et al., 2012, Smook et al., 1996, Venselaar et al., 2015), innovation through procurement (Burke and Miller, 1998, O'Connor et al.,

2014), energy transitions (Kemp et al., 2007b, Killip, 2013, Faber and Hoppe, 2013) and economic logic and principles (Bygballe et al., 2013, Wu et al., 2019, Koskela and Vrijhoef, 2001).

In the Netherlands innovation in the construction industry became mainstream after the collusion scandal in the early 2000s (Dorée et al., 2003, Pries and Dorée, 2005, Rutten et al., 2014). However studies on off-site construction are limited, Halman et al. (2008), Hofman et al. (2009) for example theorized about the benefits of off-site construction in the Netherlands and developed a supply chain model for off-site construction respectively. Nevertheless, it is still unknown, in the context of the Netherlands, the challenges, barriers and mitigating strategies relevant to the adoption and change process of off-site construction. Moreover, the possible roles that the Dutch government can assume to incentivize and promote the adoption of different off-site technologies are still unknown.

1.2.2 Objective and deliverables

Given the situation outlined in section 1.1. and the lack of research regarding the role of the state in incentivizing the adoption of off-site construction, the objective of this thesis was to determine what could be the role of the government in the process of adoption of off-site construction. By understanding the role of the government and the available instruments, the authors proposed a policy recommendation based on theories of innovation adoption and technology diffusion. Therefore it is expected that this research project will deliver a *set of policy recommendations* based innovation theories that will help reduce uncertainty at the firm and system level to improve the conditions for the uptake of off-site construction.

1.2.2.1 Main research question

The literature review presented in section 1.2.1 shows that in the case of the Netherlands, there is a knowledge gap on what could be the role of the government in the adoption process of off-site manufacturing. Therefore, with this thesis, we intended to bridge the gap by answering the following question:

"How can public policy instruments at national and local levels help to overcome the barriers for adoption of off-site manufacturing in the construction industry of the Netherlands?"

1.2.2.2 Sub-questions

The main research question cannot be answered trivially or directly. To answer this question, first, several sub-questions need to be answered. The following section details the sub-questions that were answered in the spirit of answering the main research question.

1. What is off-site construction and how the benefits relate to the problems of the construction industry in the Netherlands?
2. What type of innovation is off-site construction?
3. What actions can states take to support and improve innovation?
4. What roles and instruments can be used to incentivize innovation in the construction industry?
5. What is the current state of the construction socio-technical system in the Netherlands?
6. What are the adoption barriers in off-site construction?
7. What can we learn from past global experiences and the current push for more off-site construction in the UK?
8. What roles and instruments can be used by the government to bridge the adoption barriers of off-site construction?

1.3 Approach

This thesis project used an *exploratory case study* approach. The reason to select an exploratory case study is that this type of case study can be used to generate a hypothesis that can be used in other case studies (Johannesson and Perjons, 2014). Within the possible types of case studies, the selected case study would be a critical case study, where the precondition dictates that the case study will allow the researcher to

"achieve information that permits logical deductions of the type, 'If this is (not) valid for this case, then it applies to all (no) cases." (Flyvbjerg, 2006).

The case study is based on the perception of different actors in the construction industry about the barriers and challenges of adopting off-site construction. We aim to consolidate the fragmented and varied perspectives of actors in the construction industry. By generalizing knowledge, we mean that the insights gained during the development of the case study will help to make a hypothesis about different perspectives in the wider context of the construction industry (Barnes et al., 2020).

1.3.1 Research methods and data requirements

To answer the main RQ, we divided it into smaller sub-questions, which were answered through the use of different methodologies and theories. A brief explanation of the research methods and theories proposed for answering these questions is depicted in this chapter.

To understand the value and areas of application of this research, first, we need to understand what are the benefits of off-site manufacturing and why is it needed to respond to modern societal challenges. Given that there was enough historical and research data in scientific literature to answer this question, the better-suited method was to conduct a state of the art literature review on off-site manufacturing.

Because we considered off-site construction as an innovation, we conducted a literature review on innovation, the rationale for innovation, the creation and diffusion of innovations and the change process that leads to change. We will draw a framework based on innovation theories that combined the systems of innovation approach and the system transformation approach.

Then tried to analyze the construction industry as a socio-technical regime. Published and grey literature was used as a source of information to create a snapshot of the dynamics of the construction industry. Stakeholder analysis will be conducted to determine the roles stakeholders play in the innovation process in the construction industry.

We used literature on off-site barriers experienced in other countries to derive a list of barriers that were tested later among construction industry stakeholders. We then tried to determine what are the perceptions among different stakeholders about the adoption barriers of off-site construction based on the literature and their own views. Interviews were conducted among leading users and/or potential users of off-site products.

The last sub-question made use of the information gathered in the case study, the framework and theories investigated in previous sub-questions and generated different policy recommendations based on possible roles that the state can take when incentivizing the use of off-site construction.

1.3.2 Limitations of selected methodology and data

Two main methods of data collection were used during this research. The first, literature review, is usually the basis of any research and provided in-depth knowledge about the topic of off-site construction and innovation theories. However, published literature in the construction industry proved insufficient, and grey literature provided a good, although probably biased, source of information. Because of the relevance of the construction industry in society and its considerable market power, much of the grey literature that umbrella organizations publish aim to provide the views of its members considering their main interest and positions on different topics. Therefore this source of information was carefully considered and analyzed for possible sources of bias.

This limitation is what guided the process of using interviews as a complementary data collection method. Interviews can be useful instruments to collect in-depth knowledge about a topic and can provide greater insights than expected. Nevertheless, the interviews were hard to achieve. To overcome this, careful considerations of the suitability of the interviewees' trajectory and relevance to the topic studied was performed to ensure the quality of information. To improve the reliability of the results, we have triangulated the answers of the interviewees with the findings in the literature, aiming to corroborate the views of interviewees with pre-published information about offsite construction.

Another limitation is that even if the interviews are correctly selected, they do not hold the answers that we might be looking. There is no assurance that the interviewee had in-depth knowledge of the topic that is being studied, or under the focus that the author is studying it. These challenges, along with time constraints, presented a limitation for the researcher to provide solutions that can be used without further confirmation and clarification.

1.4 Link to CoSEM

The focus of the CoSEM program and in particular the track 'Built Environment and spatial design', is the design of solutions and interventions in socio-technical systems for modern problems and challenges in the built environment that are present in the private and public sector. Through the careful consideration and analysis of the opportunities and limitations that public policy, systems engineering, multi-actor decision-making, innovation and technological developments, the CoSEM program provides the foundations to analyze the symptoms of a socio-technical problem, understand the different challenges that need to be addressed to solve a problem and finally to design an inclusive and effective solution.

The process of adoption and diffusion of technology has different dimensions. In the particular case of the construction industry, these dimensions include a wide range of different actors, institutions, large economic stakes, a fragmented process of decision-making and a large social impact (Koebel et al., 2004). These factors make the study of the process of innovation and technology adoption in the construction industry complex.

In this thesis, we have studied the challenge of housing provision through the lens of construction technologies. To do so, we made use of qualitative research methods that are an integral part of the CoSEM program. Moreover, we took a holistic view of the perspectives and interest of different actors.

The link between the CoSEM program and this thesis lies in the characteristics of the problem studied. Innovation in the construction industry is a multi-disciplinary, institutionally diverse, multi-actor problem that needs to be addressed as such. Moreover, the participation of the industry in the wellbeing of society and its impact on the everyday life of people creates multiple perspectives that need to be merged and considered to provide effective solutions. The results of this thesis is the design of intervention through policy recommendations for the government the incentivize the adoption and diffusion of off-site construction.

1.5 Research outline

Chapter 2 studies the concept of off-site manufacturing, its history, principles, benefits and challenges and how this relate to the current problems of the construction industry. Chapter 3, motivates the type of change that might be required in terms of innovation typologies. Chapter 4, investigates different rationales and approaches that can be taken to address problems in the innovation process. Chapter 5 examines the roles of the state and how public policy instruments can be used to address innovation problems. Chapter 6 describes the current state of the construction industry in terms of innovativeness and systematic failures that inhibit innovations. Chapter 7 introduces the empirical work conducted during this thesis and the finding from it. Chapter 8 describes the lessons from previous developments in off-site construction and recommendations made by the UK. In chapter 9, different recommendations about the role of public authorities are presented based on key activities in innovation systems, transformational management change and strategic niche management. Chapter 10, concludes about the relevance and insights discovered in this thesis. Chapter 11 discusses the scientific and societal relevance and reflects on the limitations of the project and its implications in the results.

2 Off-site construction and the construction industry

2.1 Introduction

Off-site construction is not new. The concept was developed in the early 19th century and currently forms part of the innovation agenda of many countries (Goulding and Arif, 2013, Oorsprong, 2018, Ministerie van Landbouw, 2019). The promotion of off-site construction responds to a need by governments and industry actors to tackle problems of affordability, sustainability, productivity, among others (Goulding and Arif, 2013, Barlow, 1999, Goodier and Gibb, 2007, Zhai et al., 2014). The need for changes in the construction industry is where multiple actors see the potential to develop and incentivize the wider uptake of off-site construction. Despite the claimed advantages, and except for some nations like Japan and Sweden, adoption remains low (Goulding and Arif, 2013).

The possibility of revolutionizing and providing opportunities to the construction industry to help it fulfil its societal role has recently claimed the attention of several state and non-state organizations in the Netherlands and abroad. These organizations are paying more attention to the developments of this technology around the world to learn and move towards its adoption (Bujis et al., 2019, Bernstein et al., 2011, Van Weersch, 2020, The Housing Forum, 2004).

Currently, the construction industry in the Netherlands faces pressure to provide more houses. Some groups argue that up to one million homes shall be delivered by 2030 in order to supply the increasing demand created by a growing population, changes in demographics, years of undersupply and the deterioration of current building stock (Hall and Vidén, 2005). While off-site construction is not a definitive answer to the problem of undersupply and low productivity, a move towards the wider adoption should help reduce long term uncertainty of the supply side. Additionally, it should help to reduce the mismatch between demand needs, an increasingly less suited labour force and quality problems that are typical of traditional construction methods.

Chapter 2 focus is on explaining how the concept of off-site construction has developed through the years, its paradigms, benefits and how it can improve the shortcomings and challenges of the current construction industry.

2.2 Off-site construction history and definitions

2.2.1 Historical background

The first development in off-site or prefabrication came in 1833 with the London firm H. Manning offering "Portable Colonial Houses" (Ågren and Wing, 2014). Development of the industrial revolution allowed engineers and architects to explore and experiment with new fabrication and transportation methods (Ågren and Wing, 2014). The fabrication of building components was in an "on-demand" fashion, and this translated into a new cost-effective method of construction. In 1853 Joseph Paxton designed the Crystal Palace, which made use of cast iron and glass in a modular configuration to overcome the scheduling constraints that limited construction time to six months (Ågren and Wing, 2014). Nevertheless, even when the project proved to be highly successful, the methodologies developed were not suitable for large joint projects. The ideas of Paxton lacked transferability to other projects, and this resulted in the industry not being able to adapt and implement them (Ågren and Wing, 2014).

In the early 20th century, the industry saw leading architects made use of prefabrication techniques to design small houses (Ågren and Wing, 2014). At the time these developments seem to set a new standard in construction productivity, however, possibly due to the economic downturn that followed the First World War they were unable to gain more traction (Ågren and Wing, 2014). Moreover, this push for modernization of construction methods was faced with negativity by workers, who impulse by fear of losing a share of their jobs ended up boycotting the project.

Off-site construction received a new opportunity in Germany due to the severe housing shortage following WWI. Buildings were considered as sub-assemblies, aiming at optimizing the use of materials and logistics. However, this economy-lead innovation and housing production resulted in low-quality housing that had severe faults and defects (Ågren and Wing, 2014). In the Netherlands off-site construction, in particular precast concrete, helped rebuild the infrastructure damaged by the war and, in a point, it managed to achieve over 50% of the market share in housing developments (Pries and Dorée, 2005). However, after the need for extensive construction projects ceased, the attention moved to small scale staking system (bricks, especially limestone) (Pries and Dorée, 2005).

At the same time, Buckminster Fuller and Konrad Waschmann established the way to the methods that are we currently use in modular construction (Ågren and Wing, 2014). One of the main ideas that lives up to this day was to use the minimum amount of components while achieving maximum flexibility. A "General Panel System" was developed, however in practice these innovative ideas proved too challenging to be implemented and were not able to be scaled to a commercial setting (Ågren and Wing, 2014).

The last architectural driven development came in the form of Open Systems Housing, where the main idea consisted in building not based on what the industry considered to be the next step but on building based on what the industry could not foresee (Ågren and Wing, 2014). This idea is what is currently being pushed by many proponents of off-site construction, arguing that in order for off-site to be successful it should limit the power of architects and give it to the final client in the form of flexibility (Hofman et al., 2009).

2.2.2 What is off-site construction today?

Off-site construction can be described the construction method where components are prefabricated off-site in a factory environment and then transported and assembled on-site (Goodier and Gibb, 2005, Ferdous et al., 2019). These elements can be as complicated as modules with the size of one or several rooms or simpler elements like prefabricated concrete elements. In basic terms, the types of off-site construction can be characterized based on the level of off-site works they have. In comparison to traditional on-site construction, we can set a continuum where the lowest level of prefabrication is on-site construction and the higher volumetric (modular) buildings.

When the level of prefabrication rises, the intended benefits of off-site can be achieved more effectively. Volumetric systems are the type of technology that optimizes the added benefits of a factory environment. For example, for the case of on-site labour requirements, McKinsey & Company report that up to 90% of on-site labour could be moved to a factory if volumetric systems are used. At the same time, it is not clear if such change can be achieved, in theory, this benefit (on-site labour demand) should increase (decrease) when the prefabrication also increases (Bertram et al., 2019, The Housing Forum, 2004). Figure 2 depicts this relation in the case of on-site labour.

The uptake of these products tends to be higher in the lower levels of completion since the type of components and systems reflects and adapts more to the 'traditional' construction systems (Goodier and Gibb, 2005). A higher level of prefabrication usually requires a change in relations between clients and suppliers, while integrating market demands, design, production and information flows in the building process to achieve mass customization in housing (Lessing et al., 2005). For example in the Netherlands hybrid systems are commonly used, especially walls and slabs, however because of the low level of prefabrication, the relationships and methods tend to follow 'traditional' construction instead of off-site construction processes.

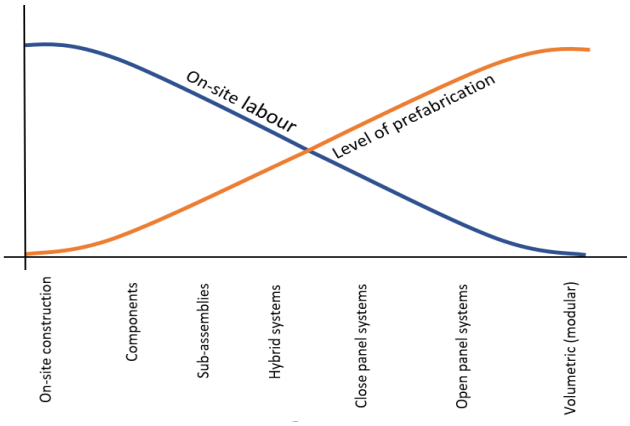


Figure 2 On-site labour demand in construction (own figure)

Lessing et al. (2005) define eight paradigms and concepts that characterize modern industrialized construction. These paradigms and their level of implementation are helpful to understand how the system of industrialized housing works. These paradigms are defined to help understand how the system works and how companies can evaluate themselves in their level of implementation. From these paradigms, we can consider seven out of the eight to be relevant in terms of off-site construction, since the principles help understand how the adoption of off-site technologies affects the supply chain in construction (Lessing et al., 2005). In order to understand the system better, we explain these paradigms, except for off-site manufacturing of building parts, since it is contained within the idea of off-site construction. Therefore, according to Lessing et al. (2005), these paradigms are explained in Table 1.

Table 1 Paradigms of off-site construction

Paradigm	Value to off-site construction
Planning and control of the process	In order to adopt and implement off-site construction the processes of "design, manufacture, assembly and other related processes" must be structured and managed early in the process, since the early management of these processes determines the possibility to optimize the benefits and characteristics of off-site construction.
Developed technical systems	Off-site construction requires that the products are designed, developed and tested in separate settings to the final products. The technical development of these products can then be integrated to building systems, where the aim is to integrate and create synergies between elements of the building in order to obtain the higher level of flexibility and production in a factory setting.
Long-term relations between participants	The practical implementation of off-site requires the establishment of long-term relationships between actors in the construction supply chain. These relations determine how fast teams can adapt and start projects. This cooperation allows actors and producers to save time in the production and tendering process.
Integration of supply chain management and construction process	In off-site construction, the supply chain is divided into two parts, the pre-assembly and supply chain of factories and the construction site supply chain. The proper implementation of off-site in the construction industry requires a high level of integration between both, and by doing so, factory efficiencies to improve. Moreover, this integration should result in projects that can actually be completed in less time.
Customer focus	One of the main issues with off-site manufacturing and construction has been the lack of customer orientation, as proven by the programs implemented in the UK after WWII and Sweden in the Million homes programme (Lessing et al., 2005). Therefore, it is clear that a customer-oriented approach where the right products are delivered to the right market is needed. Many times the customer focus is lost since most of the project requirements in the construction industry come from a client and not the end-user of the product (Hartmann et al., 2008).
Use of information and	In order to adjust the supply chain of off-site construction, information must be reliable and accurate along the process. Innovations and developments in the field of information and

communication technology	communication technology, like BIM tools, allow manufacturers and contractors to provide the right flow of information to all the actors involved in the supply chain.
Systematic performance measuring and re-use of experiences	Off-site construction requires that actors involved can determine mistakes and errors in the building process. For off-site to be effective, there is a need for staff from all companies or actors involved review their experiences and technical challenges during the whole process. Controlling the performance and using previous experiences allows companies to improve in the know-how of processes.

These paradigms are vital characteristics of off-site that any actors looking to adopt off-site must master and implement in their organizational culture in a continuous and project basis. These factors are interrelated and should be considered as a set of paradigms where the effective performance in one will result in better implementation of the others (Lessing et al., 2005). Many of these paradigms relate to the barriers of adoption, reflecting that companies and actors find it difficult to organize around this paradigms and to integrate them into their business model.

These interdependencies affect all the actors in the supply and demand chain, and therefore, there should be a careful understanding of the parties involved in off-site construction. The following section, we explain the actors that participate and are involved in the process of off-site manufacturing.

2.2.3 Stakeholders involved in the supply chain of off-site construction

Off-site construction involves several stakeholders, similar to the process of construction with additional actors involved in the manufacturing process and delivery logistics of components. In order to review actors that participate in the construction industry, we will divide them into demand-side actors and supply-side actors. Additionally, in the construction industry, we can refer to clients as a third group of actors since they might play a role in the demand, supply and as the link between both. Demand-side actors are connected to supply-side actors through clients since in most of the cases they are not the end-users of a product. According to Hartmann et al. (2008), clients are those actors that initiate, commission and pay for projects. Clients play a significant role in the construction industry, usually having direct input in the planning and construction stages of a project (Hartmann et al., 2008). Actors in the demand side of the construction industry, may not only influence the production process, but they might also act as barriers when trying to minimize risk in projects (Hartmann et al., 2008).

Demand-side actors in the construction industry are in most of the cases the general public, who represent the intended user of a product. The actors in this group are highly heterogeneous and have fragmented needs. This fragmentation causes 'clients', as mentioned above, to take the role of eliciting requirements of end-users and transferring them to supply-side actors (Hartmann et al., 2008). Since the scope of this projects is not to study the transfer of needs from end-users to clients, we will limit to acknowledge that end-users are commonly misunderstood in the construction industry and that the supply of construction products is not always aligned to the needs of the end-user.

The construction industry is a highly fragmented one, and this can be mostly seen in the supply-side stakeholders where different actors participate and coordinate their activities based on clients requirements to come up with a product that suits the needs of final consumers (Hartmann et al., 2008). Wu et al. (2019) identify fifteen actors that belong to the supply chain of off-site construction projects. However, they include end-user or residents, which in this case are considered to be part of actors in the demand side. Among these actors, and of particular importance, we have general contractor, subcontractors, local government, architect, supervisors, components manufacturers, financial institutions, logistics contractors, property management companies and developers (Wu et al., 2019).

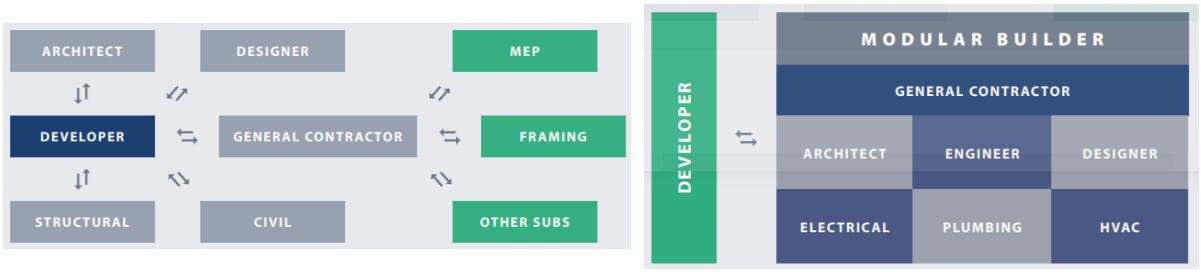
Usually, developers are what can be considered as clients, since they produce houses as assets in build-to-sell formats or build-to-rent formats. Among this group of actors in the case of the Netherlands, we have housing associations, which are actors in charge of producing houses for low-income groups in build-to-rent schemes.

Additionally, there are actors like insurance companies, certification agents, and labour unions who may play a role in off-site construction processes, working as enablers or hinderers of innovation (Arif et al., 2012).

Actors in the supply chain can be integrated into single entities. These entities perform many of the roles that the collection of actors above perform but in an internal manner. The adoption of off-site construction requires that actors in the supply chain establish several new relationships based on the business model they decide to pursue. The Boston Consultancy Group in a publication named "The off-site revolution in Construction" identifies that these business models for off-site construction can be divided into two main types, ecosystem coordinators and end-to-end providers (de Laubier et al., 2019).

These business models relate to the level of vertical integration that companies have. BCG proposes, another way of classifying the different business models, end-to-end providers can be classified as systems suppliers of turnkey projects. Ecosystems coordinators is another type of business model that is comparable to the role that is performed by contractors in traditional construction. In a case study done in China by (Wu et al., 2019), social network analysis showed that many actors consider the contractor to assume this responsibility for off-site construction. This similarity brings several advantages in off-site construction since many of the infrastructures that contractors have is already centred around the coordination of components, materials and products. Of particular importance, in this case, is that many contractors could re-arrange their operations to fit better the requirements of off-site construction, however, on the client-side the re-arrangement of organizational processes and coordination of work might require a more burdensome process.

The modular building Institute present a simple differentiation between the traditional business model of the construction industry and a representation of the business model of a modular building. They argue that the current construction industry is designed for task separation, and the off-site construction industry should represent integration along the supply chain (Build Offsite, 2018). Figure 3, depicts this difference between business models.



Traditional Off-site

Figure 3 Comparison between Traditional and Off-site construction business model (Build Offsite, 2018)

2.2.4 Drivers of off-site construction

Much focus has been given into the understanding of what could be the advantages of off-site construction (Goodier and Gibb, 2005, Goulding and Arif, 2013). Despite this strong focus on understanding the benefits, some authors like Goodier and Gibb (2005) and Arif et al. (2012) point out to the fact that actors in the construction industry still misunderstand many of the benefits.

This lack of understanding of the drivers can be derived from conflicting information and historical developments that have caused that drivers are usually seen as ambiguous and in some cases, contradictory (Pan and Sidwell, 2011). In an attempt to clarify where the possible source of confusion and why these drivers are seen as ambiguous we explain next the main drivers as determined by Goodier and Gibb (2005) and how these drivers could be seen as possible sources of ambiguity.

Decrease construction time: off-site provides the opportunity to decrease construction time-on-site and overall schedule by up to 60%. While the overall planning and scheduling time might involve similar timeframes when compared to traditional construction, the time spent in physical activities realized on-

site are usually reduced by transferring large amounts of work from the building site to a factory environment.

Increased quality: the consolidation of works that are done in a factory environment allows the quality of components to be improved. The fragmentation and division of work that is typical in traditional construction methods opens the possibility for quality issues and mistakes. Quality controls for on-site construction tend to be less rigorous than in a factory environment. The incorporation of technologies like Building Information Modeling (BIM) and 3D printing allows precision engineering to be incorporated in a field of engineering where traditionally large tolerances are considered and accounted for in the design phase.

While the inclusion and implementation of technologies and quality control measures that can be achieved in a factory environment improves the overall quality of products delivered, there tends to be a large bias when considering off-site. It is hard to pinpoint to a single reason for this misconception, however as we explained in the previous section several projects and entire programs were mismanaged in the last half of the previous century and actor have anchored their perception towards them.

More consistent product: similar to the benefit of improved quality, factory environments allows greater precision and quality, making off-site products more consistent in their delivery and production. On the other hand, actors tend to confuse consistency with standardization and repetitiveness in the built environment.

Reduce snagging & defects: traditional construction requires the interaction and intervention of different specialized labourers to deliver a product, the coordination and control of the activities tends to be insufficient to ensure that defects are minimized. Additionally, because of the nature of construction works, some of the products will not show defects immediately, but several hours or days after the labourer has already moved to another section or job. While defects and the process of snagging are inevitable, off-site construction promises to deliver products that are consistent and with a lower number of defects once the product leaves the factory.

Although if properly applied, this principle can reduce the problems associated to buildings after they are delivered, however, the significance of a mistake in the design or manufacturing process tends to be amplified due to the repetitiveness of the process. Some actors consider this to be a risk too high to assume and given the lack

Increase value: the use of off-site products can increase the value of a building by providing a constant stream of products that are more easily maintained but at the same time can provide a life cycle cost greater than of traditional construction products. Life cycle value of the products tend to be higher since the decommissioning part of the building can be done in a way that the materials are recycled and not disposed of as in traditional construction.

Increase sustainability: construction waste is one of the main contributors to landfill waste. Additionally, the waste that is produced by demolition cannot be given a second life. Off-site construction, on the other hand, can be designed to have an afterlife once the building has reached its final life. Moreover, the logistics involved in traditional construction are large contributors to the emission of greenhouse gases. While off-site construction is not immune to the emission of these gases, the supply chain can be optimized to improve the efficiency of each trip and to avoid unnecessary movements. To this, we can add the possibility to control the emission of gases in a factory environment and the possibility to use electrical equipment for logistics and installations required to be done on-site.

While the net use of materials when comparing both types of constructions is not fully understood, off-site can make use of more innovative materials like products produced by 3D printers or timber products that most of the times are assembled off-site. The problem with off-site is that technically the products are not optimized to provide the same kind of transfer of forces like monolithic or on-site construction. Therefore, off-site products tend to be redundant in their design, making use of more materials than in traditional construction.

Reduced initial cost: cost reduction is one of the main issues of off-site construction since many actors tend to consider it more expensive at the beginning than traditional construction. However, if industrialization and standardization of components are achieved, products can be mass-produced and the fixed cost of factories optimized. While in the short run, it is difficult to see off-site as a solution to construction cost, in the long term, it should be able to provide cost optimization.

Reduce whole life cost: similar to increased value, the use of off-site construction allows designers to plan for better re-use of materials at the end of the lifespan of buildings. Together with improved quality and reduction of defects, off-site should reduce maintenance and operation cost. Additionally, maintenance schedules should be more precise and reactive maintenance should be diminished because products should be able to fulfil functional requirements in a better way than on-site construction.

Increase flexibility: while on-site construction will not be replaced for buildings that are designed to have special architectural requirements, off-site provides the opportunity to involve end-users earlier in the process, allowing them to make explicit their requirements and demands. To achieve flexibility similar to the one that traditional construction methods provide industrialization of the production should be as advanced as the levels seen in the car industry. Even then, traditional flexibility, as seen today in the construction industry might not be achievable; however, under the added social and technical benefits of implementing off-site construction, a change in mentality should be welcomed.

Greater customization options: related to flexibility costumers should be able to optimize their spaces according to their needs if involved early in the process. While variation and customization are seen as one of the main drawbacks of off-site construction, current technologies are being developed to include not only functional requirements but at the same time turn off-site construction into a direction that allows a customer-focus while mass production is fully utilized.

Increased components life: increased quality, reduction in defects and better handling of components should result in a longer lifespan. On the other hand, actors main concern with components life is that because traditional construction is seen as more 'robust' and long-lasting when compared to off-site products, there is a misbelief that traditional construction can stand for longer than off-site. However, on the other hand, there is a lack of understanding between design service life and actual service life.

While these benefits tend to relate to the contrast between traditional construction products and off-site construction products, there are added benefits that can only be considered at the system level. These added benefits represent the core of the idea towards the move and need to change from traditional construction to off-site construction. For example in the UK, several reports (Postnote, 2003, Tresury, 2003, Farmer, 2016) indicate that if the housing needs of the UK are to be fulfilled using Modern Methods of Construction, that revolve around off-site technologies, should be adopted. Next, we describe how off-site construction can answer to these needs and other needs that the current regime of construction supply has not been able to answer.

2.3 Modern challenges for the construction industry in the Netherlands

The construction industry has been for long catalogued as an industry with low productivity growth (Barlow, 1999, Halman et al., 2008, Farmer, 2016, Winch, 2003). While this does not mean that the construction industry in unproductive or has low productivity, it do reflects a possibility for it to do better in the face of modern challenges. Orstavik et al. (2015) point out that in order to do better, actors in the construction industry must "wake up" to the challenges and opportunities of modernity and use innovation as the motor of change and prosperity.

Moreover, countries face new challenges to ensure the wellbeing of its inhabitants. Among these challenges, we find ageing working forces, low housing supply and an increase in international competition. Additionally, the construction industry faces structural problems that limit its ability to fulfil its societal function (Boelhouwer, 2019). The problems that the construction industry faces are, among others, slow response to demand signals and requirements, poor predictability, rising construction cost

that affect affordability, low-profit margins, underinvestment in innovation, declining infrastructure quality, rising sustainability concerns and insufficient capacity (Halman et al., 2008).

An ageing population and access to labour play a significant role in the capacity of the construction industry to deliver projects. Additionally, the strong dependence that the society has to the providers of infrastructure has caused prices to rise. This model of dependence of large flexible workforce is to be tested now that we are getting closer to Brexit. While the effects on seasonal workers and access to foreign labour in the UK are unknown, it is expected that much of the workforce will stop being available in the mid to long term (Farmer, 2016, European Comission, 2018). Because of the strong economy in the Netherlands, it is expected that much of this workforce will try to look for work opportunities here. This makes the issue of an ageing workforce to be a lesser urgency. However, more temporal workers mean that they need to be accommodated, either through the private rental market or through social housing. Either way, it is expected that the construction industry will not be able to keep up the pace of the demand and that the accumulated gap caused by years of undersupply (Faber and Hoppe, 2013), will make construction prices to remain high.

One of the main concerns of the construction industry is the delivering of poor quality assets, the structural fragmentation of stakeholders, lack of multi-project cooperation that allows continuous learning and competition based on price and not value, all play a role in delivering poor quality assets. While off-site construction will probably still compete in the price arena, labour and stakeholders can be better integrated with the supply chain, allowing for the transfer of knowledge from one project to the next. Moreover, the increased used in digital products ensures that better quality control methods are implemented, and fewer defects appear in the final product.

Sustainability concerns are also of particular importance since the construction industry is one of the more prominent producers of greenhouse gas emissions and waste (Klein Woolthuis, 2010). The new limits on nitrogen emissions have caused a rise in the cost of construction, which in turn makes many projects unfeasible or more expensive.

2.4 How can the benefits of off-site construction answer the challenges of the construction industry?

Historically as described in section 2.2.1, off-site construction has helped nations and governments to supply infrastructure in a fast and massive way. As pointed in section 2.3, the construction industry faces new challenges, which might be determinant in the ability of the construction industry to provide the required infrastructure. Therefore, in this section, we describe how the benefits of off-site construction could be a driver of change and help bridge the gap between modern social challenges and the capability of the construction industry to fulfil them.

Industrialized construction systems were used after WWII to provide the much-needed supply of infrastructure for countries that were severely damaged due to the war. The capacity to mass-produce elements and components allowed economies of scale and fast delivery of the required infrastructure. However, in the 70s and 80s where economic prosperity was achieved, these systems were deemed unattractive and of low quality, what forced the industry to move to more customized and project-based delivery of products. Modern technologies like BIM, the further development of timber products and 3D printing, have expanded the flexibility of products that are delivered, removing the problem of standardization and massification of the build environment.

Because of its strong economic performance, it is expected that if the local construction industry is unable to provide the services that the society demands, international actors will be interested in fulfilling their role. Globalization provides opportunities for learning and achieving economic efficiency. However, it also opens the gate for foreign firms to perform the role of local actors when they are unable to do so.

Moreover, the increase in age and the lack of interest of new labourers in participating in the construction industry creates a gap that will limit the capacity of the construction industry to provide infrastructure. On the other hand, off-site construction is less reliant on project-dependent workers, since most move

to factories, better predictability about labour requirements is achieved and can be incentivized with the right instruments.

Off-site construction relies less on heavy machinery, and the manufacturing of products is done under controlled environments where emissions are more easily controlled. Furthermore, because off-site construction is produced under manufacturing conditions, there is a better use of raw materials. In contrast, the construction industry is one of the biggest producers of waste (Li et al., 2014).

In summary, we can conclude that the current production model of the construction industry has several bottlenecks, which if unattended, could cause a systematic under-supply of built environment products. Therefore we see that the adoption of off-site construction could lead to more streamlined supply chains, multi-project learning, less reliance on a flexible workforce, less waste and better alignment between sustainability concerns and production methods. Moreover, the construction industry will face stronger competition from actors that will be interested in supplying the Dutch market, which might prove efficient for society but detrimental to the industry.

3 Off-site construction as an innovation

Off-site construction represents a change in the way we build, using a manufacturing approach that is closer to the one used in the car industry that to the one currently used in the construction industry (The Housing Forum, 2004, Winch, 2003). This change involves a re-structuring of relationships in the supply chain, the development of new products, the coordination of regulation that better suits the nature of off-site and several other factors that are interrelated and interdependent (Goulding and Arif, 2013). The Housing Forum (2004) is empathic concerning the change that is required to implement off-site construction, claiming that "*[the organization]… has to be prepared to do things differently".* Understanding off-site requires not only a deep understanding of the technical challenges the technology will face but more importantly, an understanding of the paradigms and forces that shape the adoption of off-site construction. In the next chapter, we provide an overview of the type of innovation based on the current practices of the construction industry.

3.1 What is innovation?

Innovation is a concept that is widely defined in the literature; however, the definitions can be conflicting and depending on the context of the system different definitions might be better suited to answer to the question of what is innovation (Sexton and Lu, 2012). According to Sexton and Lu (2012), policy-makers see innovation as a concept that entails the 'successful introduction of new services, products, processes, business models and ways of working'. Edler and Fagerberg (2017), see innovation as the introduction of new ideas or solutions. However, they point out that these solutions come as a 'response to problems, challenges or opportunities that arise in the social/ economic environment'. To complement these ideas, we take the concept brought forward by (Rogers, 2003) where 'newness' is relative and irrelevant to the adopter, since, from a behavioural perspective, the only important factor is if the innovation is perceived as new by the individual. In the context of off-site construction, this addition is relevant because it provides the link between an idea that has been around for a few hundred years and the relative newness of it within housing and construction industry actors.

While innovation is seen as a motor for economic growth, it is essential to note that in most of the cases innovation also presents high risk and can determine to success or survival of an enterprise (Orstavik et al., 2015). Innovation at the macro level provides wide benefits for society. On the other hand, it is commonly overlooked that not all innovations work and end up being realized and adopted by society. This dilemma creates a problem since the society needs innovation to improve its wellbeing, but commonly the developers of innovations face a significant risk when investing in changes to their current business models (Orstavik et al., 2015). Therefore, it is essential to note that there is a gap between what is best at the societal level and what is best at the organization level. Additionally, since we cannot assume that all investments in innovation are to succeed, we should not assume that the incumbent actors in the social system should all consider that investing in innovations is the best path forward.

Moreover, as explained by Tornatzky et al. (1990), the decision to adopt is based on different contextual elements that create uncertainty. The decision-maker of an organization will usually decide to move forward, only when the decision environment provides enough clues and shows that either benefits or pressures are evident and not adopting a technology represents a risk (Tornatzky et al., 1990). Decision-makers or senior management in the construction industry hold particular relevance since many innovations in the industry are usually the main drivers of innovations (Lenderink et al., 2020a).

3.2 What type of innovation is off-site construction?

Edquist (2011) argues that innovation policy should be based on policy objectives. Policy objectives vary depending on the type of innovation that is being addressed. He distinguishes between different types of innovation and how they affect the strategies and policies that are to be implemented. In the next section,

we describe the type of innovation that we are addressing in comparison to traditional construction practices and products.

The first typology of innovations that are defined by Edquist (2011) is whether an innovation is 'new to the world' or 'new to the firm'. As we described in the previous section, off-site construction is not a new concept and has been used to fulfil different needs throughout history. While off-site construction has been widely used in the past and present, the concepts and paradigms behind off-site construction differ from what the current construction industry does. The current construction business models provide an example of how off-site construction might differ. As we pointed out in section 2.2.3 current construction is organized based on the separation of tasks and the provision of unique products, on the other hand, the business model of off-site construction represents the provision of 'standardized' products through a highly integrated supply chain.

The next type of innovations that need to should be identified is whether an innovation is radical or incremental. Tornatzky et al. (1990), defines incremental innovations as innovations that can be introduced by implementing only minor adaptations of existing organizations routines. Radical innovations are processes that require the development of entirely new routines, that might affect systems of belief and value systems of organizations.

Within this context, off-site construction represents a radical innovation since the implementation of off-site construction requires not only moving the production of components from in-situ to a factory but also a change in the production mode and the distribution of labour in comparison to the current modes of production (Winch, 2003).

The next type of category that should be distinguished is whether the innovation is high-tech or low tech. Off-site construction if compared to other industries like manufacturing or retail might be low-tech, however, when compared to the traditional construction industry, it can be classified as high-tech. The change in technology is mostly due to the type of developments that have made off-site construction attractive to modern societies. In the Netherlands the use of BIM, that is one of the principal 'high-tech' components of off-site construction, is already widely adopted (Siebelink et al., 2018), on the other hand, components like the use of robotics and precision engineering like the one used in the car of manufacturing industry are not commonly used.

The next categorization of innovation, as defined by, Edquist (2011), is whether the innovation is a product or process innovation. Off-site construction, in comparison to traditional construction, represents both, a process and a product innovation. Tornatzky et al. (1990) define a product innovations as the innovation where the product is the innovation by itself, and process where the innovation comes in the form of an instrument to achieve something else. As we described before, in the section of benefits of off-site construction, we described how the products should be improved by the use of off-site construction, either through a reduction of waste, improvement in quality or any of the other associated benefits. However, we also pointed out that the distribution of labour and the task should be redesigned. Moreover, the traditional practices that are embedded in the construction industry should be adapted from project-oriented to continuous production (Winch, 2003).

While this classification provides an overview of the complexity of the change required, it fails to acknowledge one of the main components of off-site construction. Off-site construction also requires the restructuring of relationships between suppliers and clients, at both interfaces (i.e. between suppliers and developers (housing associations) and between developers and final costumers. This process of redesigning and restructuring relationships with customers can be considered as a service innovation. Flikkema et al. (2007) define service innovations as *"the multi-disciplinary process of designing, realizing and marketing combinations of existing products with the final attempt to create valuable customer experiences"*. Considering that off-site construction represents a service innovation too, not only adds an extra level of complexity to the problem but also allows us to understand that off-site construction will require a change that goes from production to delivery and customer experience.

In summary, we can identify off-site construction as an innovation that is new to the firm, radical, high-tech, both process and product and that requires the creation and re-invention of services to cater the new requirements and relationships caused by the implementation of off-site construction. This short analysis has shown that if off-site is to be adopted, multiple stakeholders, practices, routines, institutions (rules) should be addressed. In the previous chapter, we reviewed why we considered off-site construction to be a possible solution to the problems of the construction industry in the Netherlands. In this chapter, we have argued that there is a large gap between traditional construction and off-site construction and that the policy problem goals should be based on a problem that needs large change in practices and paradigms of the construction industry. In the next chapter, we will focus on identifying how change happens and how can the state incentivize it.

4 Rationale for public intervention

In the previous chapter, we described how off-site construction represents a radical change from the current practices of the construction industry. Radical innovations at the system level might require the involvement of a wider arrange of actors and stakeholders. Because of the influence that innovation has for economic performance, growth and more recently as an answer to grand societal challenges, it has become mainstream within policy-makers (Edler and Fagerberg, 2017). Policy is seen as a tool able to influence innovation. Specifically, innovation policy has been the focus of many scholars in recent years, noting that although innovation has been around since the beginning of humans, policies that aim to have a direct effect on it have only recently surfaced (Borrás and Edquist, 2013).

Recent innovation theories have grown apart from the idea that innovation is a linear process where, first, comes the scientific discovery then the development of applications and finally this applications come to be used by actors in the industry (Tornatzky et al., 1990). However, the process of innovation is more complex than this and has little to no lineal development. On the other hand, just assuming that innovation is complex provides little value to the process of understanding it. Therefore it is required that we understand how the environment interacts with social constructs and how we can manipulate them to achieve progress (National Research Council, 1992, Geels, 2004).

In the next chapter, we first discuss the rationales for innovation policy, based on the needs and understanding of the process and value of innovations, and provide activities listed in the literature as key components of the process of innovation. Then we reconcile the different approaches and rationales under the perspective brought forward by Weber and Rohracher (2012). We finalize this chapter by consolidating a list of activities that are to be supported by public authorities to promote, incentivize and diffuse innovations.

4.1 Rationale for public intervention in the innovation process

Innovation policy, as a separate topic, has only recently gained attention (Edler and Fagerberg, 2017). Nevertheless, policies that have had an impact on innovation systems have been around for a long time. The reason for the new attention on innovation policy comes from the fact that policy-makers now see innovation as an indicator of economic performance and as a precursor of economic growth (Mazzucato, 2016). Moreover, policy-makers are more interested in designing policies that can not only incentivize the creation of knowledge and technologies but also on how these policies shape markets, create the right conditions and provide support for innovation to take place (Edler and Fagerberg, 2017).

Classically two main streams explain the rationale for innovation policy (Edler and Fagerberg, 2017). Market failure and innovation-system are commonly cited as rationales for the implementation of innovation policies (Edler and Fagerberg, 2017, Mazzucato, 2016, Sexton and Lu, 2012, Borrás and Edquist, 2013). More recently the need for sustainable innovations and large socio-technical change gave rise to the idea that if a large change is required, we should not only limit ourselves to look at failures in the market or system, but we should also consider changes that happen at the aggregated level that hinder the rate of change in societies. Weber and Rohracher (2012) call this approach aggregated level transformational policies. We will describe next the three approaches above and how they relate to the need to provide and support 'key activities' to the innovation process.

4.1.1 Market failure approach

After WWII and seen the success of the investments made by the US and UK governments, several academics argued that investment in innovation should not be limited to warfare but should have a broader perspective and approach (Edler and Fagerberg, 2017). However, economist argued that if the payoff of such investments were so large the industry should be the ones undertaking them. Nonetheless, the RAND Corporation argued that knowledge is the most important source of innovation could be

accessed by anyone, subsequently limiting the rewards that market parties could extract from the creation of it (Edler and Fagerberg, 2017). The perspective on markets failure arose because the rewards of investing in the creation of knowledge could not be fully extracted by market parties, and in many cases, a sizeable social impact was underutilized. This underutilization signalled a failure in the market and brought the view that intervention was needed in order to incentivize innovation (Edler and Fagerberg, 2017).

Three main instruments were designed to address this market failure, being: the development of basic research, where rewards could not be easily or readily accessed; subsidizing R&D in private firms, as a way to reduce the risk of investments; and the improvement of property rights regimes (Edler and Fagerberg, 2017). These instruments have been widely used and adopted, given their simplicity (Edler and Fagerberg, 2017). However, several authors argue at the same time that interventions from public bodies are not better than the natural development of knowledge, especially since the information is usually less available to these bodies.

This approach although widely used is at odds with the fact that empiric research has shown that most of the problems of innovation are not in the development of knowledge but in the actual implementation of it (Mazzucato, 2016). Mazzucato (2016), acknowledges these limitations and extends the need for policies not only to address the market failures but at the same time, shape the markets. Additionally, she recognizes that the market failure approach aims at solving problems for markets as if they were in a 'steady-state' and does little to 'shape' dynamic and changing conditions which are commonly found in the markets.

4.1.2 Innovation-system approach

After the economic stagnation of the late '70s and the '80s, many scholars brought forward the idea that innovation could play a larger role in making economies more dynamic and competitive (vis-à-vis other nations) (Edler and Fagerberg, 2017, Schot and Steinmueller, 2018). This idea made policy-makers more aware of how innovation could affect economic developments and revitalize economies. Based on ideas from Schumpeter that innovation can act as a driving force for economic and social change, several economists started to see innovation as this driving force that could be shaped by policy (Edler and Fagerberg, 2017). Although Schumpeter saw the environment as a constrain for innovation, the new proponents of the innovation-system approach argued that policy could contribute to the development of innovations by shaping and interacting with the environment (Edler and Fagerberg, 2017). This push for a better understanding of innovation systems led to the development of the National innovation system approach. The National Innovation Systems explains that at the system level (nation) firms depend on resources, activities and socio-cultural constraints happening at this geographical level (Edler and Fagerberg, 2017). Moreover, the realization that geographical or specific industry-related constraints bound innovation gave rise to the even more specific regional or sectoral analysis of innovation activities (Schot and Steinmueller, 2018).

Zooming-in even more and to produce a more strategical vision of innovation the concept of 'Technological innovation systems' (TIS) has recently come to the discussion (Bergek et al, 2018a as in Weber and Rohracher, 2012). TIS are socio-technical systems that focus on the development, adoption and diffusion of a specific technology. TIS revolve around specific functions that aim at providing solutions to systematic failures in order to allow improved system growth and performance of the innovation system (Weber and Rohracher, 2012). Several authors have proposed what these activities are, initially seven activities where introduced, and later these were expanded to include ten main activities divided into four main groups (Development of knowledge, demand-side activities, provision of constituents for systems of innovation and support services) (Borrás and Edquist, 2013, Edquist, 2011). A brief description based on Edquist (2011) of the importance and role of these activities is presented in Table 2.

Table 2, Key activities in systems of innovation

Development of Knowledge	Creation of new knowledge	R&D provides the basis for radical innovations. Basic research, applied research and experimental development are all required to create alternatives to the incumbent products/processes.
	Competence building	Labour and organizations need to adapt and learn how to use products. Universities, vocational institutes and organizations all play a role in the development of competences.
Demand-side activities	Formation of new markets	Innovations might not have specific markets or markets might not be developed enough to ensure the ideas and products can be adopted and diffused.
	Articulation of requirements	Defining quality requirements from a demand perspective opens opportunities for new ideas to provide solutions. Articulation of demands steers innovations into the desired direction.
Provision of components for Systems of innovation	Forming and changing organizations	Innovations diffuse through the forming of new organizations by entrepreneurs, or by adapting and increasing the competences of incumbent organizations. Public policy plays a role in simplifying the "rules of the game".
	Integrating new knowledge into current systems	Under typical conditions, firms do not innovate by themselves, but form networks and relationships with other firms. Knowledge is transferred in these networks allowing feedback loops that lead to optimization of an innovation.
	Forming, changing and adapting formal institutions	Institutions provide incentives or obstacles for innovations. Adapting these formal institutions promotes dynamism in the system.
	Providing incubation activities	Markets usually are not capable of nurturing and incentivizing innovations in the early stages. Therefore, public institutions must provide 'safe' environments for innovations to take place.
Support services	Providing financing for innovations	Finance provides the required capital for innovation activities to develop. However, markets are usually inefficient in providing capital for high-risk, high-uncertainty developments.
	Creating and supporting consultancy services	Consultancy services are usually done by private actors, providing knowledge and expertise that helps minimize uncertainty.

The TIS approach is usually centred around specific technologies and runs the risk of overlooking interactions and changes needed for large socio-technical change. While this approach might provide useful insights into the process of technological diffusion and adoption of a specific technology, the policies and actions needed for large transitional and systematic change fall out of the scope of the approach. Weber and Rohracher (2012) argue that because of these shortcomings, there is a need for a perspective that is integrative of socio-technical dynamics. The Multi-level perspective aims at providing a better understanding of the needs and dynamics of socio-technical systems.

4.1.3 Transformation-system approach

Transformation systems approach recently came into the picture, given the shortcomings of the two previous approaches to deal with grand societal challenges (Geels, 2019). This approach to innovation policy builds on the Multi-level perspective. The multi-level perspective on innovation systems is a framework that is used to analyze and understand the processes that occur in socio-technical systems that lead to innovation transformation in the system and the adoption of innovations (Weber and Rohracher, 2012). The main focus of this perspective is to broaden up the scope of analysis that is common in traditional innovation theories (Geels, 2011).

4.1.3.1 The multi-level perspective on innovation systems (MLP)

While theories of diffusion of innovations tend to centre around products and organizations the MLP main foci of analysis is the network of organizations that are contained in industries, sectors and economies that form 'socio-technical systems'. The socio-technical system is defined, contained and bounded based on the interrelated, complementary and interdependent products, agents, built-in knowledge, technologies, internal and external firm's mechanisms of interaction, processes of selection and competition and institutions (systems of rules) that structure interactions (Geels, 2004). Geels (2004) separates the socio-technical system in two main components, the production side and the function/user side (see Figure 4). The framework makes use of multidisciplinary and multi-organization units of analysis to establish the required network and infrastructure of rules that are necessary to develop, commercialize and adopt innovations (Geels, 2004). The different levels of analysis refer to three aggregation levels: niches, regimes and landscapes. Next, we explain how these levels are defined and how they interact.

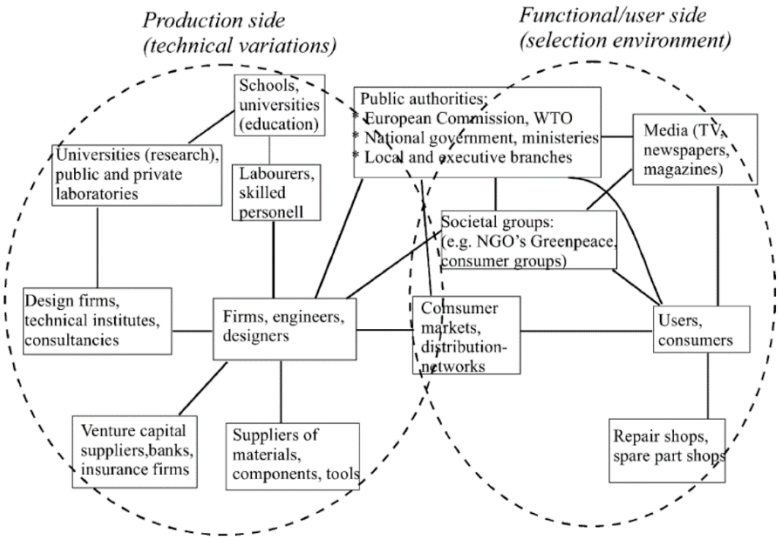


Figure 4 actors in the socio-technical system

4.1.3.1.1 Socio-technical Regimes

At this level, we find the institutions, actors, tendencies, infrastructure and behaviours that structure the status-quo system. Actors actions are shaped and coordinated by the systems of rules in place and their interpretation and interaction. This level is characterized by stable, locked-in behaviours that allow innovations to only occur at an incremental pace. Regimes are conformed by different sub-regimes like political, economic, cultural, social, scientific and market conditions. This level focuses on capturing the coordination and interaction that occurs between them. This means that not only these sub-regimes have their own independent behaviour and developments, but they also interact and co-evolve with each other (Geels and Schot, 2007). While this process of coordination and alignment between sub-regimes creates stability, it also opens opportunities for tensions that create windows of opportunity for radical innovations to take place (Geels and Schot, 2007).

The stability in socio-technical systems creates barriers for change and innovation (Geels, 2004). These barriers arise because actors have commitments and interest in maintaining the status quo. These interests and commitments might be represented through sunk cost, like the built-up knowledge of the system, investments in infrastructures, partnerships and patterns of interaction (Geels, 2004). Additionally, actors are bounded by the systems of rule in place. These systems of rules shape the innovation space. Three main types of rules have been identified that create stability in the system and limit the actions carried out by actors (Geels, 2004). Cognitive rules are in charge of creating the design space, forcing incumbent actors to work in the 'traditional' way. Normative rules, shape the behaviour of actors limiting their

capacity to behave in ways that are against the tradition. The third types of rules that create stability are regulatory and formal rules, like contracts or legally binding agreements.

An additional mechanism of stability relates to the embeddedness of current artefacts that create their own sub-systems of complementariness and behaviours that accumulate inertia and therefore are hard to change (Geels, 2004).

4.1.3.1.2 Niche innovations

This level describes the developments where technology is developed (Geels and Schot, 2007). Developments in this level are carried out by actors who are hopeful that if a window of opportunity arises, they will be able to fit the market demands with their solutions and developments. Within this space, solutions are formulated in the way of visions and expectations that aim to provide an answer to different social issues (Geels and Schot, 2007). At the same time, the proponents of these solutions start creating their own markets, complementary activities and social networks that support the adoption of the technologies developed. Because these innovations might not be aligned with current market conditions, different learning and articulation processes are developed in order to structure the alternatives developed and the demands of the market (Geels and Schot, 2007).

Actors at this level are 'hopeful' that a window of opportunity will arise since regime conditions tend to limit through 'lock-in' mechanism and inertia the applicability of innovations developed at this level. Windows of opportunity might arise when the articulation of the capabilities of the innovation becomes more evident, and therefore, actors at the regime level see the innovation as stable. Another way that windows of opportunity arise is through external shocks to the system that bring social needs that cannot be answered through solutions in the regime level (Geels and Schot, 2007).

4.1.3.1.3 Socio-technical landscape

At this level, we find the system characteristics that work at a higher external level than niches and regimes. While developments at the landscape level influence the regime and niche levels, these tend to find it much harder to do the same the other way around. This is because, in the landscape context, we find developments that are embedded in society and tend to have a much slower response to external changes.

4.1.3.2 The process of change

The process of innovation adoption tends to follow a general pattern where developments at the landscape level provide incentives for technologies at the niche level to gain momentum. This momentum allows them to become mature enough. At the same time, these developments affect the stability of the regime and open windows of opportunity for technological innovation to root itself within the regime (Geels and Schot, 2007). This double effect allows elements of the regime and innovation to become aligned. These process and patterns are depicted graphically by Geels and Schot (2007) in Figure 5.

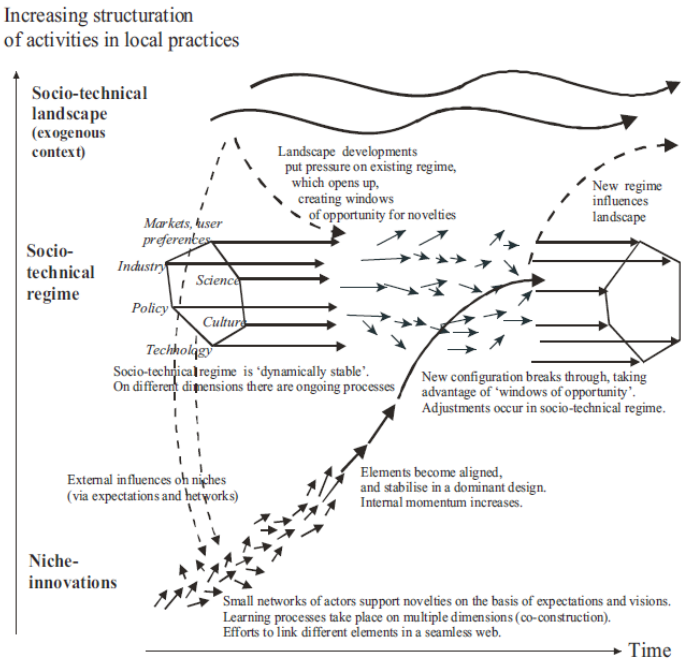


Figure 5 Multi-level perspective on innovation systems (Geels and Schot, 2007)

4.1.3.3 Approaches to achieving change in the system's transformation

Transformation at the system level requires the coordination and cooperation of actors at different levels. In contrast, market failures and innovation systems focus on analyzing failures in the creation and supply of innovations and fail to consider the necessary change for certain types of transformations to take place. With innovations that aim at transforming the system more focus is needed in determining the challenges and coordination problems that arise from the variety of actors involved in the process of innovation (Weber and Rohracher, 2012). Moreover, the focus is on the creation of windows of opportunity by altering conditions for niche level innovations to be more attractive for regime level actors. The transformation-systems approach reflects on the fact that if a change at the system level is expected there should be coordination of policies, a clear direction of change, integration of demand, coordination of institutional change and long term reflectivity about the uncertainties of innovation.

The literature on sustainable transitions and innovation, as an answer to grand challenges, calls for innovation policy to play a role through two main sets of activities within the transformation process, strategic niche management (Schot and Geels, 2008) and transition management (Kemp et al., 2007b).

4.1.3.3.1 Strategic niche management

Strategic niche management (SNM) focuses on the activities that are needed to nurture and protect technological developments in the early stages where uncertainty is high and the dynamics of the system act as destabilizing forces (Schot and Geels, 2008). While SNM was developed in line with the MLP, it shares multiple similarities with the TIS perspective (Kivimaa and Kern, 2016). Both approaches' main goal is to stabilize the environment and provide support in the creation, development and adoption of new technologies. Smith and Raven (2012) define SNM as the provision of a protective space. This protective space is of particular importance for upcoming technologies that are path-breaking and are not able to compete and tend to fail against existing embedded technologies used in the socio-technical regime. Three main processes are defined in literature as being key to nurture and protect niche innovations: the articulation of goals and expectations, helping networking processes and assisting in learning processes (Schot and Geels, 2008, Smith and Raven, 2012). Table 3 introduces these processes and gives the rationale for the importance of each process.

Table 3 Key processes for nurturing niche innovations

Articulation of expectation and visions	Niche development requires long term vision and directionality. Articulating the visions creates attention, legitimizes the process and opens learning opportunities.
The building of social networks for long term goals	Niches require networks and operation arenas to attract outside actors, investment and resources. Moreover, this provides opportunities for the niches to be tested and improved.
Learning processes	The creating of knowledge and information is valuable, however, moving from first-order learning to changes in the cognitive frames and institutions is needed to achieve adaptation.

4.1.3.3.2 Transition management

Transition management calls for a broader approach, not focusing on how to improve the conditions for upcoming technologies to enter the system but focus more on structuring and delimitation of goals, followed by the definition of long-term visions and goals (Kemp et al., 2007b). This approach calls for more substantial and comprehensive forms of governance (Kemp et al., 2007b). Negotiation and mutual adaptation under this perspective are seen as convenient for mutual gains but incapable of achieving fundamental and structural change needed for sustainable transitions without providing strong and long term commitment among the involved parties.

Within the context of the Netherlands, transition management is currently used by the Dutch government to deal with the transition to low carbon energy systems (Kemp et al., 2007a, Kemp et al., 2007b). Transition management deal with steering problems. Similarly to the activities presented in Table 2, these problems need to be addressed by actors within the system to allow for deep systematic change to take place (Kemp et al., 2007a). In Table 4, we explain the key problems that need to be addressed in the transition management approach based on steering problems

Table 4 Transition management steering problems

Coordination of discourse	Large changes in the socio-technical system have conflicting views on goals, means and nature of the problem at hand. Because of the uncertainty about the process, continuous and iterative articulation of expectations is needed.
Definition of long term vision and goals	Current network management focuses too little on long term goals and too much in the process. Because control is distributed, creating mechanisms for mutual understanding can help to define the long term goals while providing flexibility for short term capabilities.
Forecasting and backcasting of system	Changes in socio-technical systems come with uncertainty. Creating strategies based on needs but also in capabilities provides the opportunity for discovering paths, setting long term goals and identifying alternatives.
Management of portfolio options	Commitment to one alternative might create lock-in and escalation of commitment. Managing alternative options provides flexibility if a change is needed.
Development of transition arenas	Transformational change takes time. Political interests are usually more urgent and have a short term vision. Therefore, the focus should be on creating arenas that focus on long term goals and are outside of the short-termism of political cycles.

4.2 The policy mix

Recent scholars argue that the design and implementation of policy in practice tend to follow several approaches and a combination of different rationales, instruments and perspectives (Kivimaa and Kern, 2016). Some approaches tend to be more holistic and see the change from a meta-level perspective (transition management), on the other hand, some approaches tend to focus more on specific solutions that relate to the innovation system or the technology development space. In chapter 2, we described

why off-site construction was needed in the context of the construction industry. Additionally, in chapter 3, we described the type of innovation and how it compares to the current construction industry. We see off-site construction as an innovation that affects systems and firms at multiple levels and requires a deep structural change in the construction industry. Moreover, the rationale for change should not only be in economic growth, providing better policies based on specific context within the innovation system or providing guidance. Kivimaa and Kern (2016) argue based on the change process as seen by the MLP, that policy mixes should combine policies aimed at creating and nurturing technologies and policies aimed at weakening the current regime.

Weber and Rohracher (2012) recognize that while each approach tends to address better some failures, there is a need to combine these approaches to produce better policy mixes that are in line with modern requirements. The need for considering failures from different approaches comes from the fact that the approaches are not mutually exclusive, and they will tend to complement each other. Therefore, the policy mix should be designed to address failures at different levels and contexts. Within the framework proposed by (Weber and Rohracher, 2012), they recognize the need to combine market, structural systems and transformative failures. Table 5 presents a summary of the failures, for a more in-depth review of the mechanisms and rationale for each failure see (Weber and Rohracher, 2012).

Table 5 Socio-technical system-level failures (Weber and Rohracher, 2012)

Approach	Failure
Market failures	Information asymmetries Knowledge spill-over Externalization of cost Over-exploitation of commons
Structural systems failures	Infrastructural failure Institutional failures Interaction or network failure Capabilities failure
Transformational failures	Directionality failure Demand articulation failure Policy coordination failure Reflexivity failure

4.3 A theoretical framework of activities to achieve innovation creation, adoption and socio-technical change

In the previous section, we described why the policy mix might require a combination of different rationales and activities. The approaches presented in section 4.1 are derived from the need from these different rationales and needs. Moreover, these answer to different failures and might provide better insights into what is needed to achieve the objective and goals of policy. In tables 2, 3, and 4, we described different activities based on different approaches. Innovation policy, therefore, through the support of these activities can work as a precursor of the generation of new knowledge, acceptance and dissemination of it, to build an environment that facilitates the uptake of innovations and as a guiding instrument that reduces uncertainty and limits the influence of barriers in the innovation process.

Because of the scale and type of change that is required to adopt off-site construction, we should consider that the support and provision of these activities should help at removing failures and barriers that inhibit the development of technology and innovation adoption and diffusion. While we present here a theoretical view of how different activities might help to solve different failures, we consider relevant to note that the process of design and evaluation of policy mix is not perfect and that it should come from a process of trial and error and feedback loops between the interested actors within the socio-technical system (Flanagan et al., 2011, Borrás and Edquist, 2013).

Table 6 Key activities in transformational and innovation systems (Edquist, 2011, Kemp et al., 2007a, Schot and Geels, 2008) and the relation its relation to systematic problems (Weber and Rohracher, 2012)

Approach	Failure	Activity	
Market failures	Information asymmetries Over-exploitation of commons Externalization of cost Knowledge spill-over	Development of Knowledge	Creation of new knowledge
			Competence building
		Demand-side activities	Formation of new markets
			Articulation of requirements
		Provision of components for systems of innovation	Forming and changing organizations
			Integrating new knowledge into current systems
Structural systems failures	Infrastructural failure Capabilities failure Institutional failures Interaction or network failure		Forming, changing and adapting formal institutions
		Support services	Providing incubation activities
			Providing financing for innovations
			Creating and supporting consultancy services
Transformational failures	Directionality failure Demand articulation failure Policy coordination failure Reflexivity failure	Strategic Niche Management	Articulation of expectation and visions
			The building of social networks for long term goals
			Learning processes
		Transition management	Coordination of discourse
			Definition of long term vision and goals
			Forecasting and backcasting of system
			Management of portfolio options
			Development of transition arenas

5 Governance of change and innovation policy instruments

In chapter 4, we described how change could be achieved. We also argued that large socio-technical change that requires cooperation and coordination of multiple actors. At the same time, we presented a framework of activities that are needed to ensure that innovation and change can take place. So far, we have not discussed how the state can play a role in the process of implementation of these activities. In the next chapter, we first discuss different roles that the state can have in incentivizing innovation and supporting transformational change. Later, we present a short overview of different policy instruments and how they relate to the activities presented in Table 6.

5.1 The role of the state

The role of the state in innovation has evolved in line with the approaches of market failure, systems of innovation and transformative change. Initially, the role of the state was seen as a fixer of market failures. However, with the realization that fixing market problems was not enough, the state started to be seen as a more integral actor in the process of innovation. The first approach argued that the state needed to be reactive to failures, while the second proactive to encourage and incentivize innovation (Edler and Fagerberg, 2017). More recently, the attention towards the role of the state in guiding and shaping systems has become more prominent. Borrás and Edler (2020) argue that the need and demand for greater involvement of the state in innovation and transformation must be based on a realistic framework of the different roles of the state in order to avoid trivial and unrealistic expectations.

The approaches explained in Chapter 4, use the logic that the state should participate or intervene in the system based on different rationales. This logic, however, falls short when explaining whether the state should aim at playing a specific role or if the policy instruments determine these roles. Borrás and Edler (2020), provide a framework of different roles that the state can assume in transformational change (see Table 7). It is important to note here, that while this framework provides an overview of different roles, it does it in hindsight, and therefore fails to explain whether the state intervention is guided by the selected instruments or the assumed roles guide the selection of instruments. We consider, for this thesis, that this process is contained within a feedback loop, where the state, based on performance criteria, selects a role or instrument and then modifies its position (role), or the instrument selected in order to maximize the intended benefits or goal of the intervention.

Table 7 Roles of the state in systems transformation (Borrás and Edler, 2020)

Role	Definition
Observer	the state limits to monitor and follow the course of events in the socio-technical system.
Warner	the state identifies risks to users and the general population; then it translates these risks through a warning narrative.
Mitigator	the states actively try to limit and mitigate the adverse effects that arise as a consequence of a change
Opportunist	the state makes use of the opportunity to benefit itself for specific purposes
Facilitator	the state simplifies the change process and supports initiatives of agents of change
Lead-user	the state creates a market by making use of the innovations
Enabler of societal engagement	the states encourage and provide opportunities for social engagement through stakeholder participatory process
Gatekeeper	the state controls change spaces by opening or closing experimentation spaces
Promoter	the state acts as a champion of change

Moderator	the state acts as a moderator of narratives and positions among different social groups
Initiator	the state identifies opportunities and proactively uses its expertise, knowledge and resources to achieve transformation
Guarantor	the state provides resources against financial and/or safety risk
Watchdog	the state ensures that individual agents comply with particular collectively defined norms.

5.2 Innovation policy instruments

The need to consider public policy in the process of innovation comes from the realization that the innovation process is influenced by the context that institutions create and shape. Policymakers can act to provide better (or worst) environments to innovations to take place (Edquist, 2011). Policymakers also have interest in providing the right environment for innovations to take place, not only because innovations are motors of change and economic growth (Smith et al., 2005), but also because the systems might underperform in the delivery of social needs (Raven and Walrave, 2020, Schot and Steinmueller, 2018). So far, we have described how innovation and transformation happen at systems, the activities that need to be supported in order to achieve this transformation and the roles of the state in the governance of change. However, the question that remains is how can policy-makers influence these processes In the next section introduce how different policy instruments relate to the different activities presented in Chapter 4.

5.2.1 Instruments for systems innovation and transformational change

Policy instruments to incentivize creation, adoption and diffusion of innovations are varied, and a comprehensive review of them is out of the scope of this research. In a broad sense, and in terms of typology, Borrás and Edquist (2013) distinguish three main types of public policy instruments. The first are regulatory instruments, that make use of law and binding agreements to influence directly or indirectly creation and development of innovations. The second type is economic transfers that make use of subsidies grants, or cash in kind to incentivize positive developments. Finally, the third type of instruments are soft-instruments that focus on voluntary and non-coercive cooperation. These instruments are complementary to the first two kinds of instruments. In each of the three types of public policy, there are specific instruments, some of them overlap, and all of them interact in one way or another with each other in what is commonly called the 'policy mix' (Flanagan et al., 2011, Guerzoni and Raiteri, 2015, Nykamp, 2020, Raven and Walrave, 2020).

Edler (2016), in his book Handbook of Innovation Policy Impact, describes fifteen different types of policy instruments. He classifies them based on the objective they aim to solve and whether they work in providing support for demand or supply-side activities. While this detailed review is comprehensive of multiple policies that are used, the instruments are limited to address failures from the systems of innovation and market failures approaches. As we described before, because of the scale, type and goals of the change that is required for off-site construction, we consider that transformational policies should be included in the policy mix. Kivimaa and Kern (2016) also present a short review of how policy instruments affect what they call objectives of creative destruction. Based on the reviews of these two authors in Table 8, we present an overview of what policy instruments can be used to support the key activities presented in Table 6.

Table 8 Public policy instruments to address key activities

Approach Approach		Activity	Policy instruments based on (Edler and Fagerberg, 2017, Edler, 2016, Borrás and Edquist, 2013, Kivimaa and Kern, 2016)
Transformational change	Strategic Niche Management	Articulation of expectation and visions	Technological foresight, entrepreneurship policy
		The building of social networks for long term goals	Replacement of incumbents in advisory boards, the formation of new organizations
		Learning processes	Training schemes, educational policies, demonstration policies and subsidies
		Coordination of discourse	Innovation platforms, technology foresight exercises
	Transition management	Definition of long term vision and goals	Goal set and framing in strategies, targeted R&D schemes, regulations, labelling, voluntary agreements, innovation platforms
		Forecasting and backcasting of system	Goal set and framing in strategies
		Management of portfolio options	pre-commercial procurement
		Development of transition arenas	Innovation platforms, technology foresight exercises
System of innovation	Development of Knowledge	Creation of new knowledge	Fiscal incentives for R&D, Direct support to firm R&D and innovation, demand for subsidies, educational policies, coordination of intellectual property rights, reference guidelines for best available technology.
		Competence building	Policies for training and skills, deployment and demonstration subsidies enabling learning-by-doing
	Demand-side activities	Formation of new markets	Public procurement policies, innovation network policies, Private demand for innovation, pre-commercial procurement, innovation inducement prizes, standards, regulation, labelling, deployment subsidies.
		Articulation of requirements	Private demand for innovation, public procurement policies, labelling.
	Provision of components for systems of innovation	Forming and changing organizations	Technical services and advice, policies for training and skills
		Integrating new knowledge into current systems	Entrepreneurship policy, technical services and advice, incubators, deployment and demonstration of subsidies enabling learning by doing.
		Forming, changing and adapting formal institutions	Standards, regulations, policies aiming at structural reforms in legislation, or overarching laws,
	Support services	Providing incubation activities	Entrepreneurship policy, cluster policy, incubation, providing venture capital, low-interest loans
		Providing financing for innovations	Low-interest loans, venture capital, entrepreneurship policy
		Creating and supporting consultancy services	Technical services and advice

6 Understanding the construction industry inability to adapt radical innovations

Understanding why a particular innovation has not been adopted in a system requires that we not only focus on studying an innovation at the subsystem level (off-site construction) but to also look at the system level (the construction industry). In Chapter 3, we described the differences between traditional construction and off-site construction at the subsystem level. However, this sub-system (off-site construction) is embedded in the construction industry socio-technical system. As we described in Chapter 4, the design and implementation of policies should be based on current actors, practices, institutions and lock-in mechanisms. This analysis is necessary in order to set the context that the innovation intends to influence, but at the same time, how the forces of this context influence the innovation.

We initiate this chapter by reviewing what we call the construction industry regime. Next, we present an analysis of the different roles that actors have in the construction and the interactions between each other. We finish by defining what the system failures that inhibit the process of innovation and change, based on the findings of this chapter, are.

6.1 The Dutch construction industry regime

In the early years of the 2000s, a scandal erupted about collusion and cooperation in the Dutch construction industry (Dorée et al., 2003). Much time has passed since this scandal, however, some of the structural failures are still present and mistrust in the construction industry remains (Hermans et al., 2019, Van Marrewijk and Veenswijk, 2016). The institutional environment that led to this scandal has changed over the years to avoid issues of collusion. The government, in its role as the market regulator, developed policies and practices oriented at minimizing if not eliminating the practices that led to this scandal (Van de Rijt et al., 2010). While collusion is not seen as an issue these days, many of the structural system failures that led to these behaviours are still present, although regulated (Van Marrewijk and Veenswijk, 2016).

The Netherlands is widely regarded as a regulated market economy, where competition is seen as a provider of economic efficiency, innovation and market growth. However, given the market structure of the construction industry, companies are usually competing at the project level, which leads to undesirable behaviours (Dorée et al., 2003). While many policies have been drafted to incentivize the usage of more integrative procurements methods that replace the classic design-bid-build approaches (Dorée et al., 2003), much of the procurement is still conducted through this tool (Klein Woolthuis, 2010). Alternative ways of procurement and collaboration used in the Dutch construction industry include design-build, building team, build-own-operate and transfer and strategic partnership (Koolwijk et al., 2018, Doree and Holmen, 2004).

Positive market dynamics create opportunities for innovation and change, on the other hand, static dynamics create incentives for cost control and short-term efficiency (Dorée et al., 2003). Klein Woolthuis (2010), conducted interviews among entrepreneurs of sustainable innovations and described that innovations in the construction industry were usually incremental, and, in many cases, they were only adopted if they showed short-term economic benefit. Short-termism, combined with a highly cyclic market, create one of the structural failures of the construction industry. Investors and incumbent actors behave opportunistically to adapt themselves to the market dynamics and commonly avoid long-term visions that lead to radical innovations (Klein Woolthuis, 2010).

Cooperation in competition-driven systems is seen as a hinderer of innovation (Dorée et al., 2003). On the other hand, in a project based industry cooperation is also needed to create and develop the networks that allow innovations to be adopted and deployed beyond individual projects (Koolwijk et al., 2018).

The dynamics of the Dutch construction industry make use of cooperation in two principal ways: (1) incumbent actors build tight relationships and trust to execute projects with efficiency, while limiting external actors to participate; (2) incumbent actors 'cooperate' with actors external to the traditional networks but implement power-dependency relationships to guide and limit them (Klein Woolthuis, 2010). While this behaviour cannot be classified as static, it creates interaction failures that translate into barriers for proponents of radical innovations, since incumbents will usually fight to maintain the status-quo (Klein Woolthuis, 2010).

The construction industry in the Netherlands can be seen as being efficient under a static perspective (Dorée et al., 2003). This means that actors are capable of adapting to economic downturns by downsizing and reducing cost, while integrating vertically and horizontally to avoid excessive cost (Dorée et al., 2003). While this is efficient in the short term, in the long term, this tends to inhibit and hinder innovation and fulfilment of societal goals (Klein Woolthuis, 2010). Moreover, the construction industry-main focus is on project and project control. Business continuity is based on securing a workload (projects) and reducing operational cost if the market requires it (Pries and Dorée, 2005).

The nature of the construction industry and the type of products it delivers have caused that the main method to deliver products is through individual projects (Koskela and Vrijhoef, 2001). Competences and business models have evolved to follow the production of unique products that are no replicable and make difficult the recovery of investment from innovations that require repetition to earn back investments (Lenderink et al., 2020b).

In summary, the construction industry is conservative and tends to maintain the status quo. Actors see innovation as a destabilizing force and therefore are reluctant to innovations. While actors have the capability to change, they see radical innovation as disruptive and are unable to adjust to achieve long term goals. Moreover, actors behave to protect their short term interest and exercise their market power to mitigate or impulse innovations based on their convenience. While building regulations create barriers for innovations, they might also work in favour of actors that follow closely developments of other actors that innovate (Gann et al., 1998). Investors also have a short term vision and behave opportunistically based on the maximization of profits and not the alignment of social needs (Winch, 2003). While cooperation is present among construction actors, they do not make use of these relationships to incentivize innovation in the long term. The regime in the construction industry is traditionally conservative and tends to move away from investments that have a long term perspective and value.

6.2 The socio-technical system of the Dutch construction industry

As mentioned in chapter 2, different actors are involved and participate in the production chain of off-site construction. Additionally, we can place this sub-system in the wider socio-technical system of innovation of the construction industry. While we make use of the distinction made by Geels (2004), the construction industry cannot be divided into the two groups (i.e. production side, functional user side) into the two groups that are distinguished in his publication. However, we find that clients have multiple roles as client and suppliers of final consumers. Within this distinction, we recognize that consumers demands and requirements are coordinated and interpreted by clients, so our focus will be in the role of clients as coordinators of demand and not as suppliers of end consumers. An additional group that sits at a higher level is public institutions in their role of initiator, coordinator and regulator of built environment products, actors in this group and these roles are explained as a separate group to the ones mentioned before. The roles and mechanisms of interaction of the actors of main interest are described next in an attempt to describe how these actors could be influenced by policies (see Figure 6). We will start by describing the role of actors in the functional/user side, and then we will move to production side actors. These interactions can be linked to the diagram in Figure 6 through the numbers in []. We recognize that our interpretation of the socio-technical system is an approximation at best and that multiple actors like insurers, professional organizations, banks, labour-unions, machinery providers, tenant-unions, among others are part of the system and could influence the interaction mechanisms presented here. While we recognize the complexity and the great variety of actors that belong to the construction industry

we consider that the list presented next within the scope and limit of this type of research can provide us with the insights needed.

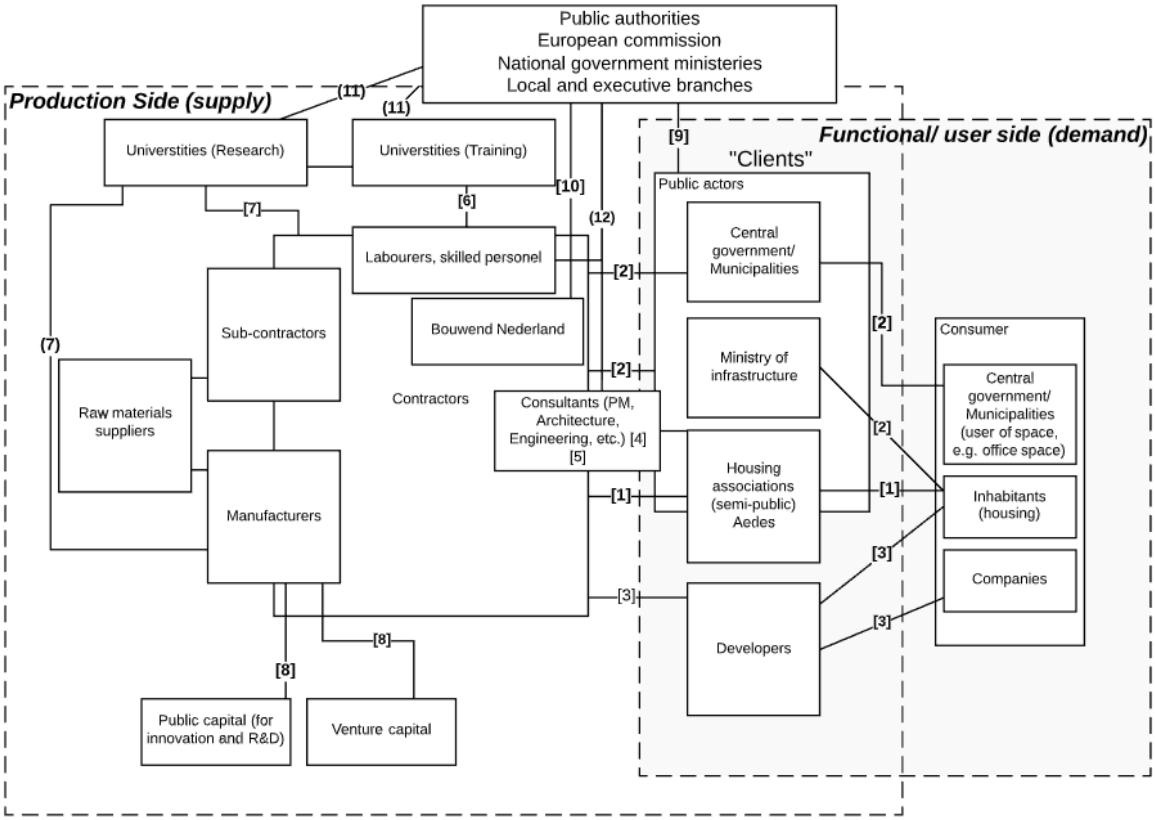


Figure 6 Construction industry socio-technical system

6.2.1 Functional/user side (demand side)

As mentioned before actors within this group can be divided into two main groups, one formed by finals consumers are the ones representing the social need for construction, on the other hand, we have clients, who coordinate and transfer the societal needs into projects. While actors in this side are not usually the main focus of innovation policies (Smith et al., 2005), there is a recent interest, especially for transformational change, on how these actors can also play a role in fostering and incentivizing innovation (Borrás and Edquist, 2013).

6.2.1.1 Consumers

Within this group, we find households, central government and municipalities as users of the built environment and business that make use of real estate to carry their operations. Actors in this group set the social needs and requirements by having preferences about the type of real estate they intend to use. Economic, demographic, preference and social changes influence the needs of actors in this group. One of the main interaction mechanisms that this group has with clients is through the expression of needs and preferences that are to be interpreted by clients [1,4,5]. Of particular interest in the adoption and use of off-site construction are these interactions, since off-site producers need to provide flexibility and align their products to the requirements of different groups. Hofman et al. (2009) found that these mechanisms should be coordinated based on four main drivers: "the degree of variety on customer demand, the extent of the required supplier investment, the extent of dependence on suppliers knowledge and the intentions of both supplier and buyer in a relationship". While these four drivers play a role at this level, they will also play a role among clients and manufacturers.

6.2.1.2 Clients

Depending on the perspective that one takes clients can have a double role in the construction industry. While end-users see clients as the suppliers of the products they make use of, contractors and suppliers see clients as the prospective demand. Clients play a crucial role in the current construction industry since they tend to influence and determine the specific requirements for buildings, limiting the possibility for repetition and replicability across projects (Lenderink et al., 2020b).

Within the group of clients, we find actors that are public, semi-public and private. Among the public actors, we find central government and municipalities who are in charge of coordinating the demand of infrastructure for the consumer [4], but also for their use. Additionally, we have the Ministry of Infrastructure and more specifically, the Rijskwaterstaat, who can be considered the executioner of civil works at the national level.

The next group of actors in the client category are housing associations, who in the Netherlands are semi-public organizations that operate under the Housing Law. This group of actors represents almost 30% of the housing stock in the Netherlands (CBS, 2019). This group of actors provides housing for low income and disadvantaged people, translating and coordinating the demand and preferences into projects [1] that are commissioned using public procurement to contractors [1]. While this group of actors is autonomous and semi-independent to the government, they are backed by government guarantees [9], which allows them to access cheaper financing, they are also regulated as public institutions. They must follow guidelines similar to the ones dictated for public clients [2]. Because actors in this group work as non-profit organizations, they tend to be less susceptible to cycles typical to the construction industry. At the same time, because they provide housing for a specific sector of the market, they have a demand for new housing that is more consistent than actors on the private side. Actors in the public side all need to obey public procurement law [2], which sets the requirements and selection procedures that agencies have to follow to select contractors when commissioning works (Hermans et al., 2019).

The next groups of clients are private developers, who are for-profit organizations that also act as interpreters and coordinators of demand [5]. Actors in this group are not subjected to public procurement procedures and are free to select contractors based on their internal motivations [3]. While this group of actors is not as regulated as public actors, they have no access to public funding as defined by European regulations. This group of actors complement most of the supply of housing and office space for un-regulated renters and owner-occupiers. However, these actors do depend partially on the provision of land that is made by public agencies, environmental regulations, permits and urban planning regulations set by municipalities. Additionally, works conducted by this group of actors need to comply with technical standards and regulations. Since these organizations are for-profit organizations, they respond to market signals rather than social needs, contributing to the cyclic provision of housing and the shortage of available investment funds when markets are down.

A group of actors that is commonly involved in organizations' decision-making in the client-side are professional consultants, who depending on the focus and size of the organization might be integrated into the organizations in this group. At the same time, they can also be independent organizations that provide their services to both clients and suppliers, or can also be integrated to contractors and suppliers. A large part of the individual actors that belong to this group is trained by local or international knowledge institutions, who set the knowledge and capabilities of professional actors.

An additional group of actors that might represent clients are independent households that prefer to develop their own houses. Because of the size and the variety of demands of this type of actors we will not describe them further in this research.

6.2.2 Production side (supply)

Actors in the supply side are the ones usually in charge of implementing innovations in their processes and products. In the specific case of the construction, industry actors are mostly represented by contractors, who have the role of providing the know-how, human resources and machinery to carry

out the requirements of clients. Additionally, in this group, we also have other actors that might be integrated into the contractor like manufacturers, consultants, and depending on the size and vertical integration of the contractors they might also perform roles that some companies designate to sub-contractors. Here we also find knowledge institutions who are in charge of training skilled-personnel and generating knowledge. Venture capital also plays a role in providing funding for entrepreneurs at the niche level with the expectation that if the ideas they provide a return on their investment will be achieved.

Additionally, we also have raw material suppliers, who are in charge of providing construction materials to contractors. Because they do not have a direct role in the innovation process of off-site construction, we will not discuss them in-depth. Next, we will describe the roles and interaction mechanisms of the main actors in the production side of the socio-technical system.

6.2.2.1 Contractors

This group of actors is in charge of materializing the requirements set by clients and consumers [1,2,3,4]. They coordinate machinery, knowledge and labour force to carry the task requested. Depending on the size and type of organization, there might integrate different roles into their processes. Additionally, these actors coordinate sub-contractors that carry out the specialized tasks based on expertise or lack of integration of the main contractor. In the current industry, large contractors tend to have specialized areas and sections for the development of off-site products, in some cases working as manufacturers of off-site products and components.

This group of actors coordinates labour, and therefore they are affected by health and safety regulations. Moreover, they depend on labour availability to carry out their task. Not only they depend on labour availability, but they tend to provide flexibility in their organizations by contracting and managing personnel on a project basis.

In the current system where price competition dominates the selection procedures contractors tend to offer their services based on lowest cost (Lenderink et al., 2020b), which in the eyes of many is seen as a source for poor quality and mismatch between quality requirements and the delivered quality.

6.2.2.2 Manufacturers

Manufacturers are actors that provide components or modules to clients or contractors. As mentioned before, they can either be part of a large corporation or be independent producers of off-site products. In the Netherlands, some examples of manufacturers are Byldis, Jan Snel, RC panels, Emergo, Voorbij Prefab, Dijkstra Draisma, among others. Additionally, large contractors like Heijmans, VolkerWessels, Royal Bam, have interests in companies that manufacture components or they have integrated manufacturing capabilities within their companies. For off-site construction to be successful the integration and coordination of stakeholders in the design and coordination of demand is needed, so while right now they tend not to have a direct impact in these processes, higher coordination should be fostered between manufacturers and demand coordinators.

6.2.2.3 Knowledge institutions (training and research)

The primary role of public institutions is to produce knowledge and distribute it. The production of knowledge is done through research and the distribution of it through training. In the Netherlands, we find two types of organizations, Research Universities and universities of applied sciences (HBO). These organizations conduct research based on commissioned objectives and through their research agendas. These organizations tend to define the capabilities of the upcoming labour force and therefore determine the level of skill that they have. Moreover, universities can conduct research that is seen as too risky for the market and provide guidance to the state about innovations.

Additional to the universities, in The Netherlands, we find the TO2 federation, whose primary role is to provide a link between knowledge and public and market actors. This organization is funded by public money but has an independent character.

6.2.3 Branch organizations and sector groups

6.2.3.1 Demand branch organizations

In the demand side of umbrella organizations, we find Aedes, who represents the interest of Housing Associations, and we have NEPROM, (Vereniging van Nederlandse Projectontwikkeling Maatschappijen) who represents the interest of private developers.

6.2.3.2 Supply branch organizations

Among sector organizations, we find a varied group of stakeholders. One of the most relevant ones is Bouwend Nederland, a branch organization that represents the interest of the construction industry. This organization works connecting different firms, research institutions and government bodies, while commissioning research in the areas of sustainability, housing, procurement practices, water mobility, among others (Bouwend Nederland, 2020).

Additionally, we find Aannemersfederatie Nederland (Contractors Federation in the Netherlands), that works as an umbrella organization representing contractors in the Netherlands.

6.2.3.3 Initiatives

Several initiatives have recently emerged that have an interest in how can off-site construction can be upscaled and implemented among the construction industry. Netwerk Conceptueel Bouwen is an organization that combines supply and demand-side actors to produce 'conceptual products'. These products are 'catalogue' products that organizations can select from different suppliers. The main goal is to make affordable living feasible again (NCB, 2020).

Additionally, the initiative De Bouwcampus is another initiative commissioned by De Bouwagenda organization to study how the construction industry can upscale the production of off-site products.

6.2.4 Public authorities

As mentioned before governments have the role of regulating, coordinating and initiating demand for products in the built environment. In their role of initiator, the government (national, regional or local) define urban planning and land availability, opening opportunities for actors to enter and produce products for the built environment. In their role of regulator, governments define binding and non-binding laws that aim at restricting the behaviour of market actors. For example, governments create or commission technical standards and set conditions for the built environment [10]. They also establish how public organization may contract and commission works through public procurement laws [9]. An additional regulation that affects, directly and indirectly, the activities of the construction industry are sustainability requirements, some of which are defined at the national level and some at the supra-national level (Europe)

Additionally, the government also acts as coordinator of demand by providing funding for activities that it deems necessary. Additionally, public authorities grant permits for the development of the built environment having a direct impact on what is built, how and where [10]. Moreover, governments can also influence the research agenda and provide direct funding for innovation.

Proponents of transformational change see the need for governments to have a more active role in the process of innovation if the structural changes that are aimed for are expected to be achieved (Geels, 2004, Geels and Schot, 2007). This active role, however, has to adapt to the current policy mix and its efficiency depends on the interaction between current and new policy mixes. Because of this for us to understand what is the role of the government in guiding and incentivizing the adoption of off-site, we must first acknowledge that policy programs are already in place. We present next, a review of the current innovation policy in the Dutch construction sector.

At the supra-national level, we find the European Commission (EC), body in charge of governing the European Union. While the European Commission does not plays a direct role in housing policies, but derogates them to the national level governments, they do play a role by ensuring that state support does

not breach the 'one market' principles. In this regard, the EC establishes the limits and requirements for public procurement and enforces competition laws to ensure a level playing field among different companies within the European Union. Additionally, the EC provides support and funding for Research and innovation.

6.3 Failures in the construction industry

State intervention is rationalized by the presence of 'failures' in the socio-technical system. As we described in Chapter 4, these rationales have evolved throughout time based on the information available to policy-makers. However, the central role of these rationales is to legitimize state intervention. In Table 5, based on Weber and Rohracher (2012), we introduced how system failures provide a rationale for the state to intervene. In this chapter, we have focused on analyzing the construction industry socio-technical system to discover why state intervention might be needed. The analysis of the regime behaviours in Section 5.1 and the actors' interaction in section 5.2 provides us with a review of the multiple failures that the construction industry has in term of radical innovation creation, adoption and diffusion. These failures are general to the construction industry and, although complementary, and in some cases, overlapping they are not specific to the adoption of off-site construction (see chapter 6). In line with the classification presented by Weber and Rohracher (2012), we classify and discuss these failures based on the evidence presented above.

Table 9 Construction industry innovation failures

	Type of failure	Failure
Market failures	Information asymmetries	(Supply-Demand) Short-term vision of supply and demand-side actors. Actors in the construction industry face hardship when economic cycles are on the downside. While this is still unknown at this moment, we can expect that the crisis caused by the COVID-19 pandemic will further exacerbate this failure in the upcoming years.
	Knowledge spill-over	(Supply) Because products in the built environment are open to anyone that participates in a project, knowledge spill-overs are common.
Structural system failure	Interaction or network failure	(Supply-Demand) Actors work in loosely coupled networks. The project nature of construction projects inhibits the possibilities to collaborate and learn. Each project in the built environment is seen as a unique product. Typical tendering and procurement methods create a fragmentation due to the involvement of professional consultants.
	Capabilities failure	(Supply-Demand) Cultural reliance on project-based mentality limits the possibilities to coordinate and create learning mechanisms. Organizations are 'locked-in' in old practices.
Transformational system failures	Directionality failure	(Supply) Mistrust in construction actors created the need to steer the system into lowest price competition. Leadership is not well articulated, and long term needs are loosely defined.
	Demand articulation failure	(Demand) Fragmented demand. Projects are commissioned based on value requirements that are heavily price sided, leaving other requirements and functions that provide 'value' as secondary decisions criteria.

Table 9 presents an overview of failures in the construction industry. These failures represent the regime level lock-in mechanism that inhibits the adoption and diffusion of niche innovations. These lock-in

mechanisms work as stabilizing factors that reinforce the practices and institutions at the regime level. Not all failures presented in the table above have a direct influence on the adoption and diffusion process of off-site construction. While they remain relevant in terms of the rationale for intervention and as challenges that need to be dealt with, we will only make use of short term vision of supply and demand, cultural reliance on project-based culture, and fragmented demand moving forward. The other challenges are to be studied in order to make the construction industry move receptive to innovations and to improve conditions for change.

7 Adoption barriers and challenges of off-site construction

Because the focus of this thesis is on how to support and incentivize the adoption of a particular technology (off-site construction), we must look at the related barriers. In the previous chapter, we took a look at the state of the construction industry and why is it difficult for actors located within this sector to innovate and change. In this chapter, we present the findings of a series of interviews that were carried among different actors in the construction industry to determine what barriers they consider to affect the adoption of off-site construction. First, we begin this chapter by describing the protocol used to gather information. Then we move to explain the findings. Finally, we end up by combining the findings of the barriers at the system level and the finding from the interviews and categorizing the barriers based on the key activities framework developed in section "4.3 A theoretical framework of activities to achieve innovation creation, adoption and socio-technical change".

7.1 Summary of activities carried out to discover off-site construction adoption barriers

In order to determine the state of the construction industry in terms of innovation, we have conducted a literature review of published peer-reviewed papers that was conducted through the database SCOPE and Google scholar, and grey literature published by different international organizations. The literature review of academic papers was done using the following strings of words: Off-site construction, Dutch construction industry, construction industry innovation, sustainable innovation, construction industry change, in combination with the Boolean operator AND. Section 7.2 presents a review of the barriers found in the literature.

In order to study how these barriers are perceived among different stakeholders in the Netherlands, interviews were conducted. Actors were selected based on their suitability to adopt off-site construction (prospective users) or their current involvement in the production of such products (suppliers). The interviews were supplemented with a questionnaire, that was distributed beforehand, that asked interviewees about their perception of off-site barriers in the context of the Netherlands. The interview protocol and actors responses can be seen in Appendix 1. Section 7.3 presents the results of the different interviews conducted among different stakeholders.

7.2 Literature review on uptake barriers of off-site construction

The barriers of off-site construction are well documented in a general context. Several studies have carried out qualitative and quantitative research into the representativeness and frequency of the barriers of off-site construction (Hwang et al., 2018). To the best of our knowledge, the barriers of adoption for the specific context of the Netherlands are still unknown, and further research is needed. However, it is still possible to derive a list of generic barriers from different studies. The following section introduces these barriers and the role they play in the adoption of off-site construction.

In total twelve different studies were analyzed (Barlow, 1999, Goodier and Gibb, 2005, Pan et al., 2007, Nadim and Goulding Jack, 2011, Pan and Sidwell, 2011, Larsson et al., 2014, Steinhardt and Manley, 2016, Choi et al., 2019, Hwang et al., 2018, London et al., 2019, Ferdous et al., 2019) and the frequency of each of the barriers described is presented below. A total of 46 barriers were identified. The most recurring barriers are: lack of certainty about the role of stakeholders (7), conflicting missing regulations (7), high logistical cost (7), increased complexity in planning and operation activities (6), the increased need for integration of stakeholders responsibilities in the process (6), lack of a culture of "design freeze" (8), client's resistance towards the adoption of new methods (8), lack of experienced suppliers (7), increased planning activities (7), negative image (7), multi-skilled labour shortage (6), higher initial cost (11), lack of flexibility and adaptability (6), a higher level of complexity in the planning process (7), lack

of "proven" products in the market (9), high capital cost (7) and increased risk (6), other barriers can be observed in Table 10 Adoption barriers of off-site construction.

Table 10 Adoption barriers of off-site construction

Barrier	Barlow	Goodier & Gibb	Pan, et al.	Nadim & Goulding	Pan & Sidwell	Larson, et al.	O'Connor, et al.	Steinhart, et al.	Choi, et al.	Hwuang, et al.	London, et al.	Ferdous, et al.	Frequency
	1999	2005	2007	2010	2011	2013	2014	2015	2017	2018	2019	2019	
Lack of certainty in the role of stakeholders	x		x	x		x	x		x	x			7
Conflicting/ missing regulation (structural)		x		x		x			x	x	x	x	7
High level of logistical cost			x	x		x	x		x	x		x	7
Complexity of process		x	x	x			x		x	x			6
Integration of stakeholders			x	x		x	x		x	x			6
Lack of information about components/systems	x	x		x		x					x		5
Logistical limitations (size)			x				x		x	x		x	5
Logistical limitations (storage on-site)			x				x		x	x		x	5
Environmental impact (long transporting distances)						x	x		x	x		x	5
Lack of financing mechanisms		x						x	x			x	4
Restrictive regulations		x				x				x	x		4
Increased need for integrated information systems				x			x			x			3
Lack of logistical suppliers to avoid monopolies				x		x			x				3
Lack of reliability of supply chain				x					x		x		3
Over-representation and use of design-bid-build contracts						x			x				2
Lack of culture of 'design freeze"	x		x	x		x	x		x	x	x		8
Client resistance	x	x	x				x		x	x	x	x	8
Lack of experience		x	x		x		x		x	x	x		7
Increase levels of planning activities	x	x	x	x		x	x			x			7
Negative image	x	x	x				x		x		x	x	7
Multi-skilled labour shortage		x	x	x			x				x	x	6
Lack of understanding of the benefits of off-site		x					x			x	x	x	5
Project-oriented construction industry culture			x			x	x		x				4
Reduction in work				x					x	x			3
Lack of understanding of how to address market conditions				x	x					x			3
Higher initial cost	x	x	x	x	x	x	x		x	x	x	x	11
Lack of flexibility and adaptability	x			x		x	x			x	x		6
Lower overall value		x		x		x			x				4
Higher repetitiveness (loss of identity)				x		x							2
High level of complexity in planning and executing process	x	x		x			x		x	x	x		7
Difficulty in achieving automation			x	x					x		x		4
Lack of required IS technology				x									1
Lack of 'proven' products in the market		x	x	x	x	x		x	x		x	x	9
Construction industry tendency not to be capital intensive			x	x	x		x		x	x		x	7
Increased risk		x	x	x	x	x					x		6
Uncertainty about off-site market consistency	x			x		x					x	x	5
Uncertainty about construction market perspectives	x			x				x			x		4
Lack of large-scale repetition possibilities			x			x		x					3
Lack of incentives to innovate	x		x				x						3
Lack of competition (suppliers)		x	x										2
Lack of incentives by public authorities											x	x	2
Land acquisition business model	x		x										2
Insolvency issues				x									1
Lack of expenditure in new construction (vs renovations)								x					1
Planning System			x										1

7.3 Interviews about off-site construction

Seven interviews were conducted among different stakeholders of the construction industry. The actors worked for the following organizations: The Student Hotel (2), Amsterdam Municipality (1), Heijmans (1), M. Architects (1), Heembouw (1) and Woningcorporatie Domijn (1).

Among the respondents, four indicated that they had more than one role, and three indicated that they had only one role. Their roles were public servant, contractor and designer. Among the others, they indicated that the role they had were: Real Estate and Development (3), contractor (2), asset management (2) and design (1).

Among the actors interviewed, all of them have had experiences using off-site construction products. The experience that actors had in using off-site products was recorded. A list of eight commonly used products was presented. The list of products included: framing systems, volumetric modular buildings, cladding systems, Bath/kitchen/toilet pods, building services, structural insulated panel systems, panelised roofing systems and foundations systems. While the range of products used varied between interviewees, they all indicated that they currently made use of more than two different products.

Interestingly three indicated that they had used volumetric modular buildings, which represent the type of off-site construction that requires a higher level of prefabrication. The two most used products were framing systems (precast concrete) and cladding systems. The use of framing systems is not surprising since the precast concrete industry is regarded as advance and to hold a large market share (Wesseling and Van der Vooren, 2017). On the other hand, the use of cladding systems (facades) is newer since the preferred method for the exterior is usually sand-stone and other types of bricks (Pries and Dorée, 2005).

The results of the questionnaire and the responses of the seven actors interviewed are analysed next. First, we will focus on the perception of the barriers that were encountered in the literature and then we will move to additional barriers that were found through open questions among the interviewees.

7.3.1 Barriers for innovations in the construction industry

The interviews resulted in the identification of two types of barriers, the first barriers for innovations in the construction industry refer to barriers that affect the general innovativeness of the construction industry and also affect the adoption of offsite construction.

7.3.1.1 Insufficient benefits v. associated risk (the chicken or egg dilemma)

Mixed reactions were obtained from this barrier; actors agreed that independently on who took the risk there was a risk too large to be justified by the actual benefits. However, they also agreed that if more 'market movement' in the off-site construction products, they will be interested in exploring these alternatives to traditional construction. On the other hand, actors indicated that they had an idea of who was to be the bearer of risk. For actors in the supply side, demand side actors should risk more by changing their investment schedules. For actors in the demand side, supply-side actors should risk more in bringing forward new products that could be adopted by them.

Actors of both sides (product and user) sides were clear in the fact that the required infrastructure to make use of this kind of products was not available. While supply-side actors indicated that the uncertainty of demand was too great for them to take the risk to invest in production facilities, actors in the demand side argued that because of the lack of available and trustworthy products in the market they could not cooperate and work in producing demand schedules that were optimized to match the requirements of suppliers.

7.3.1.2 Mismatch between investors demands and the nature of the construction industry

The construction industry is seen as highly cyclical, which affects the ability of producers to maintain a constant output in line with market demands affects the risk perception of investors. Contractors argue that the profit margin of construction activities is too narrow, hindering the ability to invest in developments. Additionally, the cyclic nature of the industry means that companies require flexibility in

their expenses, flexibility that continuous and industrialized production cannot provide. The project-based approaches provide flexibility, allowing companies to up-size or down-size in line with market demands. On the other hand, actors see production-based approaches as not suitable since factories must keep continuous production to repay the investments made to install a factory.

Moreover, supply-side actors argued that the profit margin available to construction companies limited their capacity to make resources available for investment in new methodologies of construction. Actors indicated that the current competitive environment led to companies being commissioned or tendered projects based on price exclusively. On the other hand, actors that made use of off-site products indicated that they were successful in projects where the price was not the primary determinant of selection. However, other factors, such as quality and speed of delivery, were dominant. This barrier is consistent with multiple studies (Barlow, 1999, Nadim and Goulding Jack, 2011, Larsson et al., 2014, Ferdous et al., 2019, London et al., 2019).

7.3.1.3 Lack of leadership

Actors seem to believe that innovations in the scale that is required to change the paradigms of the construction industry need more significant leadership. While they applaud the efforts made to achieve a critical mass from bottom-up approaches, they consider them too little too soft to address the main challenges that the construction industry faces. While not explicitly mentioned in previous studies about barriers of off-site construction we see similarities to barriers related to lack of government support (Barlow, 1999, Pan et al., 2007) and lack of incentives to innovate (Barlow, 1999, Pan et al., 2007, O'Connor et al., 2014).

7.3.1.4 Procurement practices

A common topic between supply-side actors, public and semi-public demand actors was that current procurement practices inhibit the possibility to select projects based on quality and/or another characteristic aside from price. One of the main problems that actors see is that while procurement practices are commonly orientated towards best value, this is assumed to be a synonym of the lowest price. Actors see the need to train and inform actors that have the responsibility of selecting tenders based on more understanding meanings of value, that not only focus on price but also integrate quality, construction nuisance, time, among others. Moreover, traditional procurement practices tend to be in the form of design-bid-build, a practice that separates the final contractor or manufacturer from the construction methodology to be used. By implementing more comprehensive procurement practices, that integrate suppliers of products and buildings, better coordination on the type of buildings that are delivered could be achieved. We find this barrier to be consistent with the findings of Larsson et al. (2014) and Choi et al. (2019).

7.3.1.5 Changes in construction paradigms

All interviewees saw off-site construction to represent a radical change in comparison to traditional construction. Interestingly the change did not come from technical issues, but it was located in the investment, coordination, requirements development, logistics or financial schedules. One of the most common perspectives is that moving from project to manufacturing requires a complete change in the organizational structures and their interaction with other actors in the supply chain. Because actors see each development in the built environment as a unique endeavour, they argue that the products available in the market are difficult to match their expectations in terms of variety. Additionally, actors indicated that the fragmentation of demand and demand requirements makes it difficult to aggregate demand in the long term. Especially actors see the mentality of public actors as a barrier to achieve standardization of products.

7.3.2 Barriers specific to the adoption of offsite construction

As we mentioned above, the interviews resulted in the identification of two types of barriers, the second type of barriers affect the adoption of offsite construction only.

7.3.2.1 Lack of certainty about the role of stakeholders and partners

Most actors do not see the lack of certainty about their role in the adoption of off-site construction. However, it was pointed out that because of the fragmentation in the processes that are carried out in the construction industry, it was challenging to place the role of others in the process and supply chain of off-site construction. This signals that actors do not have the knowledge required to find the right actor in other organizations that provide off-site products.

7.3.2.2 Conflicting/missing regulations

Actors do not see technical regulations as a barrier. However, actors do seem to think that regulations are orientated towards existing products, and they limit the possibility to design outside of the scope of products that are traditionally used in the construction industry. In general, actors seem to believe that prescriptive regulations like the ones used in the construction industry limit the design and innovation space.

7.3.2.3 Uncertainty about performance

Performance of the technical products in the market was not an issue. Three interviewed actors indicated that this was not an issue because both demand and supply-side actors were aligning to allow for suppliers to provide not only products but the after-care of them through building and operating and maintaining contracts.

7.3.2.4 Conflicting information about components

Conflicting and missing information was not seen as a significant barrier. However, one interviewee indicated that information about the interaction and coupling of different products was not clear.

7.3.2.5 Increased need for integration of stakeholders early in the process

Several people indicated that because of the time that took projects from idea generation to execution, the value of integrating stakeholders early in the process most likely would be lost. The long time needed, combined with a lack of flexibility and design freeze limitations, made the trade-off between using off-site and integrating stakeholders of little value to the project.

7.3.2.6 Design freeze limitations

Two actors indicated that because of the time that takes to develop a project and to get a building permit, freezing the design early in the process could be seen as problematic.

7.3.2.7 Lack of organizational infrastructure

Actors indicated that because of the trajectory of the construction industry and the traditions that are in place, moving from traditional construction methods to off-site construction methods required the re-definition of how their organizations work. Moreover, actors indicated that the time required to develop projects from inception to delivery made it difficult for them to assign more resources to the beginning of the project when uncertainty is high and final requirements are not well defined.

7.3.2.8 Lack of time/resources needed to integrate stakeholders early in the process

Because of the immense change that the adoption of more off-site construction technologies will require, actors indicated that their organizations could not devote resources and coordinate multiple layers in the organization to make more use of off-site construction.

7.3.2.9 A poor or negative image of off-site construction methods

While in the literature, it is commonly assumed that off-site or prefabricated construction has a bad image, actors responses seemed varied. Different actors saw the possibility to deliver higher quality products when using off-site construction. However, some actors saw consultants as the generators of the perception that off-site is of bad quality. This asymmetry of information they argue is because consultants

see their roles to be drastically modified, therefore creating a cognitive barrier when discussing the value that off-site construction could provide to the built environment.

7.3.2.10 Lack of flexibility and adaptability in the late project stages

Actors seem to point out that while flexibility and the possibility to make changes, in the beginning, is highly valued, in the late stages it tends to have little impact because most of the times the project requirements are fixed from the beginning. Two actors, however, pointed to the fact that the payment schedule that should be implemented for off-site construction does affect the flexibility of the budget. Because most costs in traditional construction are distributed towards the end of the project, the change in how the budget is spread could create financial constraints late in the project.

7.3.2.11 Higher initial cost

Among interviewees, there was a generalized notion that using off-site construction was indeed more expensive than traditional construction. Two indicated that variability in project requirements reduced the efficiency of standardization. The only actor that indicated that price was not an issue, also indicated that most of the clients they served were part of a 'niche' market where quality and long term costs were factors of heavier relevance than the initial cost.

7.3.2.12 A higher level of complexity (throughout the process)

Because off-site construction practices are orientated towards projects, and many actors have accommodated and optimized their organizations to work within this culture. The added complexity comes from actors not being able to adjust their practices and supply chains to the new requirements needed to carry out developments using an off-site or industrialized approach.

7.3.2.13 Higher risk due to the lack of information

Interviewees indicated that information was not a problem. However, they indicated that uncertainty in the market and the land provision does represent an issue when considering the planning of future projects.

7.3.2.14 Ability of products to fit consumer expectations

Two actors described consumer expectations as challenges for adoption. They argued that consumers could be described in this case as the aesthetic committees of the different Municipalities and the architects who were in charge of designing new buildings but still believed that off-site construction is limited to heavy standardized components that harm or reduce the aesthetical attractiveness of the built environment. When comparing to available literature, we were not able to establish that this barrier was relevant in any previous study. This might signal that there is a strong local and contextual dependence of the type of evaluation and permit systems that relate only to the Dutch market.

7.3.2.15 Increase risks of higher cost due to logistical constraints

The logistics required to make use of off-site products can work both as a barrier and a driver. In some cases, logistics limit the ability of developers and suppliers to deliver products effectively. A just-in-time supply chain is needed, however, given mobility constraints in brownfields the delivery of products might be compromised. On the other hand, traditional construction creates a nuisance for neighbours and given the reduction in time of activities on-site, this nuisance could be lowered. Actors are unsure of how can new logistics have an impact on environmental regulation. Some indicated that while off-site construction appears to have a higher movement of logistic activities, these activities could be carried out by electrical trucks and cranes. This barrier is consistent with the findings of multiple studies about barriers of off-site construction (Ferdous et al., 2019, O'Connor et al., 2014, Choi et al., 2019, Hwang et al., 2018, Pan et al., 2007)

7.3.2.16 Aesthetics and product flexibility

Three actors indicated that aesthetics committees requirements are usually not aligned with the range of products offered by the off-site construction industry. Urban planners usually decide on products that are in line with traditional construction methods, effectively limiting the capacity of off-site manufacturers to align with the requirements set by these committees. In line with "Ability of products to fit consumers expectations" although orientated towards a different process (urban planning), this barrier is highly local and was only confirmed by Pan et al. (2007).

7.3.2.17 Land provision

Land provision and access were discussed as a separate topic among the interviewed actors. Most of them saw land provision as an issue that, in general, affects the provision of housing and not the selection of the construction methodology. However, two actors indicated that while land access was indeed a problem for the construction industry and the provision of housing, for contractors and developers not having a continuous and predictable supply of it hindered the ability to plan and invest in production facilities (supply). Moreover, demand-side actors saw land provision as a barrier to articulate, bundle and predict demand. One actor indicated that land speculation was in line with the cyclic nature of the construction industry since actors that own the land will only make it available for development when market conditions are right. Moreover, the provision of land is also seen as a political tool for elected to officials to finance their ambitions, creating a barrier in terms of how and when land is made available for development.

Another actor also argued that while the lack of land access represents a problem, it can also work as a driver. It is expected that more developments are to be undertaken in brownfields, off-site products under the right conditions could provide additional benefits in comparison to traditional construction. The long term expectations dictated that there would be an increase in demand for technologies that are both cost-effective and neighbours-friendly. This barrier is consistent with problems about the business model of land acquisition land in the U.K. (Barlow, 1999, Pan et al., 2007).

7.4 System failures and innovation barriers

Innovation barriers can be considered to be problems in the key activities of transformation and innovation systems presented in Table 6. From the 22 barriers found through interviews and the analysis of the construction industry, we will make use of 19 barriers. From the analysis conducted in Chapter 6, we have pointed out to failures that inhibit innovation in the construction industry. Some of the failures of the construction industry in general also represent challenges and barriers that need to be tackled for the adoption of off-site construction. The interviews helped us to confirm how some of these failures also represent a challenge for the adoption of off-site construction. Therefore in the classification that we will provide next, we will combine cultural reliance on project-based mentality with changes in construction paradigms. Additionally, we will combine fragmented demand with mismatch between investors demands and the short-term vision of demand supply-side actors.

Moreover, because of the focus of this research, we will focus on 'policy problems'. Policy-problems, as defined by Edquist (2011), are dependent on two factors: (1) the existence of a 'problem'; and the capacity of public policy to act upon and influence the problem. Barriers like design freeze limitations, increased need for stakeholders involvement early in the process and lack of flexibility in late project stages, are indeed problems. However, they cannot be addressed by public policy since they represent problems inherent to the technology way of functioning. While we recognize that these barriers could be experimented and played within protected niche environments, we cannot assume that they represent actual 'policy problems'. In total, this leaves us with 20 barriers. In Table 11, we classify these barriers according to the framework of key activities presented in Table 6.

Table 11 Barriers that affect key activities in innovation systems

Key Activity	Demand-side barriers	Supply-side barriers

Strategic Niche Management	Articulation of expectations and visions	Lack of leadership	
	The building of social networks for long term goals	Lack of certainty about the role of stakeholders and partners	
	Learning processes	Lack of organizational infrastructure	Lack of organizational infrastructure
Transition management	Coordination of discourse		
	Definition of long term vision and goals		Mismatch between investors demands and the nature of the construction industry (high capital investment)
	Forecasting and backcasting of system	Insufficient benefits v. associated risk (Chicken or egg dilemma)	
	Management of portfolio options		
	Development of transition arenas	Land provision (articulation of demand)	
Development of Knowledge	Creation of new knowledge		
	Competence building	Changes in construction paradigms	Changes in construction paradigms
Demand-side activities	Formation of new markets	Aesthetics and product flexibility Higher initial cost	Fragmented and non-uniform demand
	Articulation of requirements	Uncertainty about performance Ability of products to fit consumer expectations Conflicting information about components	
Provision of components for Systems of innovation	Forming and changing organizations		
	Integrating new knowledge into current systems	A poor or negative image of off-site construction methods Higher risk due to the lack of information	
	Forming, changing and adapting formal institutions	Procurement practices	Conflicting/missing regulations. Increased risk of higher cost due to logistical and environmental constraints.
Support services	Providing incubation activities	Higher initial cost	Higher initial cost
	Providing financing for innovations		Insufficient benefits v. associated risk (Chicken or egg dilemma)
	Creating and supporting consultancy services	Changes in construction paradigms Lack of resources to integrate stakeholders early in the process	

8 Lessons from past experiences and recommendations in the UK.

In the previous chapters, we have described why off-site construction faces a hard road if we expect that the construction industry will adopt it. As we pointed out in Chapter 6, there are lock-in mechanisms that inhibit the possibility to adopt and diffuse radical innovations in the construction industry. However, and as we pointed in section 2.2.1 off-site construction has been used in the past, with different levels of success and as an answer to different needs of nations. Moreover, the advantages and prospective benefits have recently gained the attention of different governments that are faced with modern challenges. In the next section, we will describe some of the historical lessons on why off-site construction has still to become mainstream within the construction industry. Next, we introduce the vision and actions that have been proposed to address the lack of uptake in the UK. Finally, we reflect on these lessons and actions and how they relate to the context of the Netherlands.

8.1 Historical lessons

There are several lessons to be learned from these historical developments. Not only we can identify that the systems are sometimes too innovative and technically complex to be adopted by actors in the systems, but we can also point that many of the developments of off-site had to navigate through external barriers that are not inherent to the system. While actors have adopted off-site in countries like Japan and Sweden, these processes have not been without caveats. For example, 'the million homes programme' in Sweden made use of different off-site techniques furthering the development of this technology in the country. However, at the same time, a combination of toxic characteristics of the projects gave the project a negative image to the outside world, where the monotony and standardization proved to be fatal in the eyes of architects and authorities who were rapid to point, perhaps wrongly, that the construction methods were to blame and not the lack of support in parallel areas like landscaping and recreational infrastructure (Hall and Vidén, 2005).

In the UK, after the Second World War, a program implemented through the Act 1944, aimed at providing temporary housing for a short term using prefabricated and modularized construction (Goulding and Arif, 2013). Houses produced during this program had a projected life span of 10 years, and consequently, the quality requirements were not high. Nevertheless, some of these houses are still standing to this day (Goulding and Arif, 2013), and defects have shown during this time creating a misconception of low quality among stakeholders of the construction industry (Postnote, 2003).

Additionally in both Sweden and the UK, the focus was in producing elements that were economically driven and not with a customer orientation which contributed to further increase the negative image of off-site in the long term (Lessing et al., 2005, Hall and Vidén, 2005).

Given the negative image that off-site construction acquired in the second half of the 20th century, many of the developments in off-site construction moved away from the housing industry (Thomas, 2006). This remained consistent until the 80's when the Japanese construction industry, triggered by a substantial price decline in big cities along with an ageing population that limited the access to skilled labour, started using automation in building processes to achieve greater quality and certainty in the projects schedules. These developments led to the use of fully automated assembly lines, supported by the use of computer-assisted drawing (CAD) (Thomas, 2006), which to this day has led to the integration of CAD and building systems into the use of Building Information Modeling (BIM). These drivers have led to innovation, not limited to Japan, but to many Western world countries that are facing similar challenges and are in need to integrate better practices in the construction industry. These barriers have been widely studied, and many authors reflect that among industry actors, there is a generalized misunderstanding of how can innovations help solve the pitfalls of traditional construction methods.

8.2 Off-site construction in the UK

Systematic failures in the supply of housing in the UK since the early 90's created the need for the provision of more than three million homes in the UK by the 2000s (Barlow, 1999). The UK government's Barker review in 2003 argued that the social-economic impact of the under-provision of houses could have widespread consequences (Postnote, 2003). This created a new interest to develop and implement the use of modern methods of construction, which mostly involves the use of off-site technologies to improve productivity (Postnote, 2003).

The requirements of the housing market back in 2003 encouraged the UK government to incentivize and implement the use of modern methods of construction, in a document published by the Parliamentary Office of Science and Technology, it was claimed that a quarter of the houses publicly founded were to be built using modern methods of construction (Postnote, 2003). Although Government influence in publicly founded housing was able to incentivize the use of off-site construction, their influence in the private sector was more limited (Postnote, 2003). Despite the interest of the government to support the use of off-site construction, the industry uptake remained under the intended levels. More recently a report published by the Construction Leadership Council, and written by Mike Farmer, provided a review of the construction industry. The title of the report, "Modernise or die", certainly describes what he found about the construction industry (Farmer, 2016).

The report by Mike Farmed led to a review of the policies by the Science and Technology Committee of House of Lords in the UK. A summary of the recommendations presented in this report is presented next (Science and Technology Committee, 2018).

The committee identified six levers available to the government. These levers are: mandate, the use of procurement frameworks, funding conditions, sharing knowledge and expertise, regulation and research funding. Based on these six levers and on barriers that they found, they recommended that some actions were implemented. A summary of these actions is presented next.

Table 12 Recommendation by the House of Lords to improve the uptake of off-site construction

Theme	Recommendations
Construction sector Deal	Conduct a review of the demand pipeline of the construction industry for the upcoming years. The committee recommends that accountability is assigned to the ones responsible for delivering the Sector Deal. Working along with the Construction Leadership Council (CLC) to ensure that the pipeline is a success.
Digital Agenda	Provide information about the BIM mandate so that suppliers can adapt to these requirements. BIM is considered as an essential enabler of off-site construction.
Presumption in favour of off-site manufacturing	Publishing performance metrics about the effectiveness of the presumption in favour. Ensure that when projects are outside of the scope of this presumption, clear explanations are presented.
Ensuring a pipeline of projects	Ensuring that the government provides a steady pipeline of projects so the construction industry can plan ahead. Adhering to the commitments made in the Construction Sector Deal shall remain a key success factor for actors to plan.
Procuring for value	Implementing national procurement frameworks that include a variety of suppliers. Ensuring enough variety of competition between suppliers is present.
	Move forward with a joint definition of value, that can be embedded in procurement practices and includes externalities that are commonly left outside of the scope of procurement practices.

Sharing knowledge and best practice	Sharing knowledge about off-site manufacture between government institutions.
Standards	Promote the creation and distribution of recognized off-site standards.
Research and development	Working along with potential entrepreneurs and incumbent actors to ensure that the tax benefits intended for research and development are fully utilized. Assign government research funds to detailed performance data for the lifetime of buildings and infrastructure.

8.3 What can we learn from other countries?

In the first section of this chapter, we took a look into some historical lesson on how offsite has been approached and why these approaches might result in counterproductive results in the long term. As we pointed, one of the main failures in these approaches has been the mismanagement of products after its delivery. In the case of the Netherlands, this is a challenge for the areas that were built in the '60s and '70s that today are derelict and mismanaged. While it is essential to acknowledge that off-site construction might lead to some degree of standardization, which if mismanaged could result in a poor quality built environment, the focus of policies should be in providing ways to ensure that the maintenance and continuance are assured.

The case of Japan, where off-site was introduced to reduce cost and fight the decline in the working-age population, presents a good perspective on the future of offsite construction. In the Netherlands, while there is not a price decline that requires lowering costs to allow for feasibility, the focus is on lowering the cost to improve affordability. At the same time, the Netherlands, like many western countries, face an ageing population problem that will limit the ability of the industry to work effectively in the long term. What we should highlight at this point is that the Japanese construction industry biggest players in the presents have manufacturing backgrounds, signalling that the construction industry might not be the best way to approach the problem. Therefore, we recognize that policies should have a sceptic's eye and that backdoors incentivizing actors from other industries to enter into the off-site construction industry should also be considered.

In section 8.2, we moved to a more recent push for implementing offsite construction. The ideas and suggestions made by House of Lords in the UK are of interest for this thesis since they are located within similar "timeframes". Moreover, the UK and the Netherlands share some similarities that allow for the ideas presented to be considered as alternatives in the case of the Netherlands.

Among the most interesting and relevant recommendations presented in Table 12 we shall include: the construction sector deal, which should work in provide long term incentives for actors to invest in new technologies and ways of delivering projects; the presumption in favour of off-site construction, since it provides a direct and clear intention of senior leadership in the Government that an effort is being made and that the need for off-site construction goes beyond a narrative; sharing knowledge, since this should allow for different institutions to acquire the required knowledge to be able to adapt their requirements for off-site construction, moreover for the Netherlands where high degree of decision making and freedom is place on local authorities, a central state-led effort might prove too costly and fragmented to be efficient; finally, we shall include among the relevant recommendations procuring for value, since as it was reported in chapter 7, a clear definition of value must be determined in order to allow different bodies and organizations to procure with a definition of value that goes beyond the price determinant.

9 The possible roles of government in removing barriers and incentivizing the adoption of off-site construction

So far we have discussed what is off-site construction, why is it important for the construction industry, why the adoption is problematic, the current state of the construction industry and the barriers that different actors face when trying to adapt off-site construction. In the next chapter, we will go a step further and analyze how can the government at a national and local level create the 'window of opportunity' as described by Geels (2004) that would improve the uptake conditions of off-site construction and allow its adoption and the scale-up of production facilities. In section 9.2, we present a way to classify and prioritize the recommendations based on different objectives they aim to address. Finally, in section 9.3, we discuss the roles that other organizations can play in the process of incentivizing off-site construction.

The key activities for innovations, as defined in section 4.3, are were used as the basis for the analysis. We will break down each activity and recommend actions and directions of change.

9.1 Incentivizing change, removing barriers through the support of key activities

The case of the UK provides an example of the need for leadership and support that moving from old habits and activities requires. At the same time, it is not clear how these recommendations made by the UK government will play in the long run, and if actors are prepared to change, the initiative and effort forms the first step. At the beginning of this thesis, we asked ourselves *"How can public policy instruments at national and local levels help to overcome the barriers for adoption of off-site manufacturing in the construction industry of the Netherlands?".* In the following chapter, we will provide recommendations that could help remove the barriers in the Netherlands. We will centre in the activities described in section 4.3 chapter and the possible measures and instruments that could improve the situation according to the instruments described in section 5.2.1. Additionally, we will recommend different roles as described in section 5.1 that the public authorities could take. We will refer to the national level as the central government and local level as Municipal and Provincial authorities.

9.1.1 Strategic niche management: Articulation of expectations and visions

Barrier(s): Lack of leadership (demand and supply)

The government can act as a **promotor** of a consistent discourse about the need to change for more technology lead construction industry. Providing a long term vision about the needs of the construction industry should be the first step. The government should ensure that the visions are articulated and defined based on the capacity of multiple actors in the construction industry. The definition of long-term needs and expectations, together with the current capabilities and infrastructure that the construction industry has could provide a contrast between what we need and what we could expect if the current path is followed. We recommend the government act as a **moderator** to establish a commission in charge of creating the long term vision integrated by, government representatives, branch organizations like Bouwend Nederland, Aedes, the academia and labour unions. The platform BTIC currently aims to perform this role. However, the sense of urgency and the quality of the platform to transmit this message remains to be tested.

It will be of utmost importance to note that this exercise should not be seen as a name and shame exercise but as a reckoning of the structural failures and missed opportunities that the construction industry could face if collective action is not taken.

Municipal authorities can act as **promotors** by incentivizing and ensuring that urban planners work in understanding the possibilities of off-site construction within the context of housing and infrastructure.

9.1.2 Strategic niche management: The building social networks for long term goals

Barrier(s): lack of certainty about the roles of stakeholders in the process (demand), fragmentation of supply-side actors.

The government already works in providing arenas that encourage learning and exchange of ideas. An example is De Bouwcampus. We recommend the government to have an active role in **promoting** niche producers of off-site products to get involved in these organizations, ensuring that their knowledge is protected and nurtured.

Furthermore, we recommend the government act as **facilitator** by publishing guidelines about the roles of actors in Municipalities and housing associations of different sizes about their potential role if more off-site construction is to be procured and used. On the other hand, more research should be conducted on the different types of off-site construction business models from the demand side, and how can current organizations adapt their business models. Therefore we recommend the government to act as a **facilitator** and provide funding for research aimed at aligning the needs of current organizations and off-site producers.

9.1.3 Strategic niche management: Learning processes

Barrier(s): Lack of organizational infrastructure (demand)

The government could act as a **facilitator** in the creation and financing of a business advisory office that provides consultancy services for actors interested in adopting off-site. While this does not ensure that actors would approach and be willing to adapt, this could provide the 'additional' and 'temporary' infrastructure needed for the first project to start rolling.

9.1.4 Transition management: Definition of long term visions and goals

Mismatch between investors demands and the nature of the construction industry (high capital investment) (supply).

Because of the high initial capital requirements that are associated with off-site construction and the highly cyclical nature of the construction industry, investors see too much risk. The implementation of anti-cyclical housing policies that ensures a more stable demand can reduce the uncertainty about the need for better construction practices and the current capabilities of the construction industry. For example, Boelhouwer (2019), argues for anti-cyclical housing policies to help reduce social inequalities through the smoothing of the overheating peaks in the housing market. This allows the state to act as **opportunist** and take advantage of the low cycles of the construction industry to provide affordable housing. While this by itself will not create the certainty that investors are looking for, this in combination with the determination of future demand should provide more certainty about the possible demand and signal investment opportunities.

9.1.5 Transition management: Forecasting and backcasting of system

Barrier(s): insufficient benefit v. associated risk

Demand-side organizations tend to consider risk in the short term, while this expresses the short term financial health of organizations, it also tends to downplay the long term risks. Long term risk under the current model includes rising construction cost and systematic undersupply to the point where societal needs are no longer satisfied. The government, through the platform BTIC, should **promote** the definition of future scenarios, that includes the forecasting of business as usual scenarios but also the backcasting of scenarios where the construction industry is reformed. On the other hand, local authorities should carry the heavy load on this recommendations, being them the ones who understand better the local conditions and prospects. Therefore we recommend the local authorities to act as **warner** by performing this exercise of identifying possible risk through forecasting and backcasting. These exercises could help build the sense of urgency required to take into account long term risk into the decision-making process of more

organizations, especially housing associations that perform a critical role in the provision of housing in the Netherlands.

9.1.6 Transition management: Development of transition arenas

Barrier(s): Land provision (demand)

Land in the Netherlands is tied to the budget of Municipalities, while this provides the Municipalities with resources to develop projects in other areas, it also allows political manipulation. In this case, we recommend the central government to act as **initiator** along Municipalities to help disassociate the traditional model of land provision to short term political interests. Moreover, the transition to off-site construction requires long term commitments from multiple actors, and the construction industry will have to invest in providing new infrastructure, capacities, resources and the willingness to adapt in the long term. Geels and Schot (2007) point out that the transformation of systems tends to take around 25 years. Therefore we recommend the national government to act as **coordinator of social engagement** between political parties and social groups to commit to the provision long term political stability and commitment to invest in multi-period demand articulation and execution.

9.1.7 Innovation system: Competence building

Barrier(s): change in construction paradigms (demand-supply)

The project-based mentality that allows companies to adjust to the cycles in the construction industry inhibits the possibility of knowledge transfer and multi-project learning. The government can act as an **initiator** by incentivizing the inclusion of topics like design for manufacture in the curricula for engineers and architects.

Moreover, the government can act as **guarantor** and create bundling frameworks that have as main objective the reduction of construction nuisance, speed in delivery and reduction in cost. The government would provide direct subsidies for housing projects that make use of the advantages of offsite construction. Because of the fragmentation of demand and demand requirements in the construction industry, procuring for multiple projects under a single tender might prove difficult. Here we could refer to 'forward commitment procurement' in the literature, (Lenderink et al., 2019b) or to the 'presumption in favour' in the case of the UK. The presumption in favour will require a sizeable open commitment by public authorities to benefit off-site construction in the selection process. This benefit could be as substantial as to indicate that all public building should be built using these methods, or could be more gradual and limited only to housing. The right balance between both remains outside of the scope of this thesis. However, we recommend that through platforms like BTIC, a definition of suitability between off-site products and public procured buildings is developed. This flexible approach will allow suppliers of off-site products to maximize the benefits in the face of the requirements while creating learning opportunities for different actors in the supply chain.

Furthermore, clear goals, commitments, performance measures and accountability should be placed to ensure that the initial intent goes beyond that and is not forgotten after a change in the political cycle.

9.1.8 Demand-side activities: Formation of markets

Barrier(s): Fragmented and non-uniform demand (suppliers) and aesthetics and product flexibility (demand)

Several lessons can be learned from the energy transition effort made in the Netherlands. Energy labels pushed innovation and adoption of new technologies in the energy transition. One of the main issues of the current construction industry is that tender and procurement practices lead to the lowest bid to have exercise relevance in the selection process. This causes that providers of construction products and services have problems in delivering the expected quality.

We recommend the government to act as a **gate-keeper** in the creation of 'quality labels'. Quality labels might work as an enforcement tool for public procurement activities. While traditional contractors will

need to ensure that each product fulfils the requirements within the desired quality labels on a project basis, off-site manufacturers could certify their products in the factory, through the fulfilment of requirements. This could help to create a market for off-site construction products that are certified beforehand. In this way, the streamlining the approval of products that comply with the required label.

Municipalities, through their aesthetics committees, work in blocking and gatekeeping the entrance of off-site products. We recommend municipalities to act as a **promoter** of off-site products by working along with off-site producer to include their products in the aesthetics requirements. At the same time, we recommend that urban planners define standardized aesthetic requirements for collective regions.

Permits for the redevelopment of brow-fields should be adjusted to include externalities in the construction process. We recommend Municipalities to act as **gate-keepers** by including externalities in the approval process of construction permits. Off-site construction could reduce the noise and pollution nuisance caused by traditional construction practices. Moreover, the time required would be reduced, which would provide substantial benefits for surrounding inhabitants who are the most affected by the externalities caused by redevelopment practices.

In the same vein, permits, Municipalities could act as **facilitators** by creating a shared database of pre-approved off-site products to be used. We recommend Municipalities to pre-procure for products that satisfy their aesthetics and functional requirements—having pre-approved products could reduce the time needed to obtain a permit while freeing resources that could be used to integrate the demand side with supply-side actors. Moreover, this could impact the elusive private development sector, whose main objective hoovers around economic efficiency and not social long term requirements.

9.1.9 Demand-side activities: articulation of demand

Barrier(s): uncertainty about performance (demand), ability of products to fit consumer expectations (demand), conflicting information about components (demand).

As in the case of aesthetic requirements, Municipalities play a significant role in articulating and defining what the product expectations are. Additionally, architects tend to play a large role in determining and articulating demand requirements. Through the 'presumption in favour' and 'streamlined permits', architects and manufacturers would be encouraged to come up with long term solutions that can be commercialized in benefit of both.

We recommend the government act as **gate-keeper** and along with the Stichting Koninklijk Nederlands Normalisatie Instituut (NEN), to define a standard aimed at providing requirements for interfaces between products. This will standardize the performance requirements between products while allowing the experimentation of different combinations. Halman et al. (2008) argued that by providing platform approaches higher standardization of components could be achieved while retaining architectural freedom.

9.1.10 Provision of components for systems of innvoations: integrating new knowledge into current systems

Barrier(s): A poor or negative image of off-site construction (demand), higher risk due to lack of information (demand).

Despite having one of the most recognized modular buildings in the world (Hotel Jakarta in Amsterdam), the perception that off-site construction is of poor quality remains. This perception, according to the interviews, comes from consultants (architects, engineers, project managers), who due to unfamiliarity with off-site practices, tend to influence the opinion of clients. While the government can influence the teaching agenda at the university level, this might prove too little too late. Therefore, we recommend the government act as **facilitator** in the development of an off-site products database of pre-approved products where demand-side actors can select pre-approved products. We expect that by introducing such a database, current practitioners would need to quickly adapt and change if they aim to be part of the new forming market.

9.1.11 Forming changing and adapting formal institutions

Barrier(s): Procurement practices (demand), and conflicting/missing regulations (supply), increased cost due to logistical and environmental constraints (supply).

While the definition of value does not represent a formal institution, its concept the closeness to price are a given among different construction industry actors. We recommend the government to work on a more integral definition of value, that includes, among others, price, execution time, negative externalities, aesthetic value. Moving away from the lowest price might prove difficult to justify after the collusion scandal and the mistrust in the construction industry. However, recently more integral procurement practices have emerged to ensure the quality of the products delivered and the transfer of multi-project lessons through partnerships, in the new build, maintenance and refurbishment of houses.

Again we recommend the government to create, improve, change and adapt construction standards that suit the upcoming products and the new products combinations.

The introduction of more stringent environmental regulations has hurt the ability of the construction industry to deliver projects at the right price. While these regulations have a clear challenge they aim to solve (i.e. climate change), they are currently jeopardizing the provision of housing in the long term. We recommend the government to act as facilitator and create policies that are comprehensive and aim to link the benefits of off-site construction with environmental challenges.

9.1.12 Support services: Provision of incubation activities

Barrier(s): higher initial cost (demand-supply)

Because of the nature of mass production facilities, cost efficiency can only be achieved when the initial investment and the fixed cost can be distributed in a large enough amount of products. Therefore the government should provide protected space for entrepreneurs by coordinating a clear pipeline of demand. Some of the measures and recommendations could influence indirectly the pipeline of projects that are required to make off-site construction an efficient method. Nevertheless, the initial investment to set up the production facilities might still prove difficult to come by. Therefore we recommend the government to act as facilitator and provide tax-credits to housing associations through the housing levy that are willing to transfer this capital to manufacturers that are interested and willing to upscale their production facilities. The benefit could be twofold, while housing associations will get more control on the products that are delivered by manufactures, manufacturers could ask for upfront payments that would help them offset some of the cost related to the upscaling of production facilities. It remains out of the scope of this thesis the design of such instrument, along with the oversight authority that should ensure the optimal distribution of resources.

9.1.13 Support services: Providing financing for innovations

Barrier(s): insufficient benefits v. associated risk (supply)

We have previously discussed how indirectly the government could make funds available for off-site construction products. We will not discuss this further here.

9.1.14 Support services: Creating and supporting consultancy services.

Barrier(s): Changes in construction paradigms (demand)

As we discussed previously under the section of integrating knowledge into current organizations, the government could promote, initiate and finance the creation of a consultancy agency that provides support to clients who wish to adapt their business models to be aligned more efficiently with the production model. Additionally, we recommend the government to provide consultancy services for actors that are interested in life-cycle assessment.

9.2 Innovation recommendations for the construction industry, off-site construction and housing provision

The barriers that we described in Chapter 8 all relate to the adoption of off-site construction. However, the recommendations proposed in this chapter might impact innovation at different levels. Some of the recommendations described above might have an impact on the construction industry innovativeness in general and also affect off-site construction; moreover, other recommendations will have an impact on the provision of housing and also impact off-site construction. At the same time, not all recommendations of off-site construction will impact the innovativeness of the construction industry in general or the provision of housing in specific but will remain as technology-specific recommendations. This distinction between goals allows us to classify recommendations based impacts on different areas. In Figure 7, we depict these relationships based on the different goals they address. These relationships are in line with what Kivimaa and Kern (2016), describes as the destruction of stabilization mechanisms at the regime level and support of creations at the niche level. In section 6.3, we described barriers that happen at the regime level. At the same time, we have not addressed all of them since their impact on off-site construction is not direct, but they impact the general innovativeness of the construction industry. The focus of this thesis is on off-site construction; therefore, as explained in the previous section, we focused only on recommendations that have a direct impact on off-site construction.

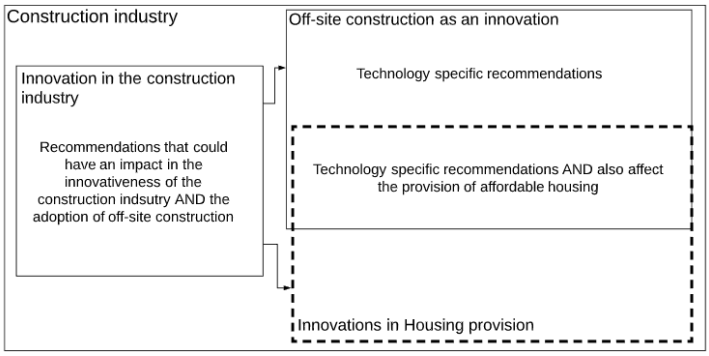


Figure 7 Recommendations based on their impact on different goals

The distinction between the impact of the recommendations on different areas allows us to address and prioritize based on specific objectives (e.g. improving the innovativeness of the construction industry, simplifying the challenges for off-site construction, improving housing provision through offsite construction). These classification aims to provide space for state actors to act based on different goals. It remains out of the scope of this thesis to determine what areas are of the most urgency for state actors to address since this process of prioritization should be carried in a cooperation process along with actors of the construction industry. Therefore, next, we will classify these recommendations based on whether they affect to the innovativeness of the construction industry in general and off-site construction, the provision of housing through off-site construction and off-site construction or off-site construction only. Figure 8 presents the classification of roles and instruments based on the goals and impact that each could have on different areas of the construction industry.

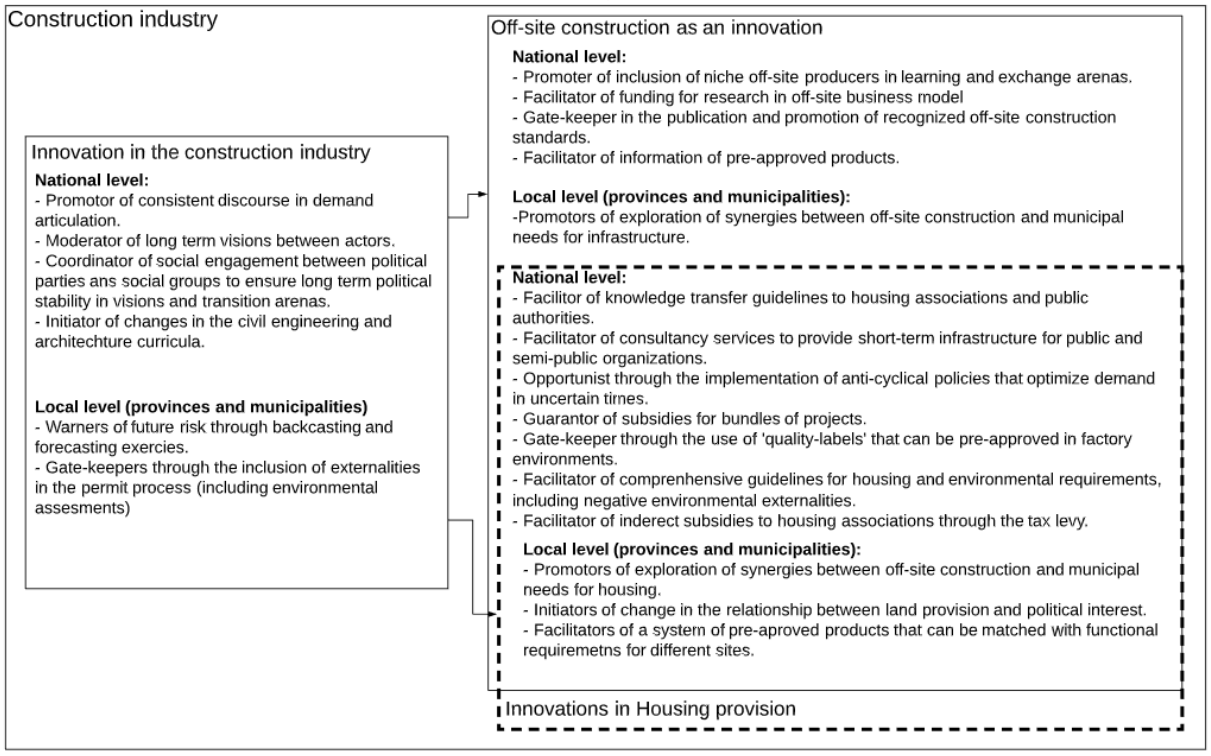


Figure 8 Goals of state roles and instruments

9.3 The roles of non-state actors in removing barriers

The main objective of this thesis is to determine how could the government, through the use of innovation policy help in removing off-site construction barriers and incentivizing innovation in the construction industry. However, it is important to note that the government, like any organization, has limitations and cannot address all the details and caveats presented here. Edquist (2011) that the activities presented before should be addressed by public and private organizations. The roles of private organizations and actors remain out of the scope of this thesis, and we will not discuss them further, especially considering that the motivations and interest of actors could be not aligned with a push to modernize the construction industry. A group of organizations that falls in the middle of being public or private and that can help in this process are branch and umbrella organizations. These organizations were mentioned above, either as support organizations or co-actors. In the next section, we will briefly reflect on the different roles that these organizations could take aside from the roles mentioned above.

These organizations currently perform specific roles that aim to fulfil their objectives. However, and as we have advocated through this thesis, we believe that these organizations, too, should adopt a system and transformational perspective. By adopting a wider stance, we believe that these organizations can realize that the change process should be a process of creation of new technologies, opportunities and collaborations, but also a process of destruction of old lock-in mechanisms and institutions that inhibit and constraint the design space.

One of the main challenges that are to be addressed is the fear that if off-site construction is to be implemented, several actors within the industry will cease to play a role. While in some cases, this would be inevitable, there is a space for new roles to emerge. We believe that organizations such as the Netwerk Conceptueel Bouwen, BTIC, Branchevereniging Nederlandse Architectenbureaus (NBA), among others, should advocate institutions in other countries to learn from their experiences and challenges. Moreover, they should aim at determining how can the actors in the current system change and adapt their current roles in an off-site construction led industry. These organizations should help in advocating for clarity in the roles that different actors in the industry could assume.

In chapter 8, we discussed lessons learned from experiences in other countries. Two of these countries are Japan and Sweden. While both have achieved high levels of prefabrication and industrialization in their construction industries, in Japan, the sudden need for re-inventing the construction industry led to the automotive and chemical industries to take over the construction industry. This change came because the existing construction industry was unable to adapt fast enough, leading to actors from other industries to move in quickly. On the other hand, Sweden provides a contrast, since the construction industry has been the one that assumed the challenges and change. The case of Japan provides some a cautionary tale about what could happen if actors are unwilling to change in the long term. Therefore, we believe that branch organizations should play a role not only by looking for new solutions but also by helping actors to find new roles and opportunities to exploit within a new industry.

Finally, as we described in section 4.3, the implementation of a policy mix should be guided and re-designed based on feedback loops between organizations and government initiatives. Branch organizations should provide a centre in determining performance criteria to evaluate the effectiveness of policy instruments.

10 Conclusions

The main objective of this research was to answer the question of *"How can public policy instruments at national and local levels help to overcome the barriers for adoption of off-site manufacturing in the construction industry of the Netherlands?".* To answer this question, we defined sub-questions that help to build up the answer to the final question. Next, we present a short answer for this sub-question and then we present the answer to the main research question.

10.1 Answering sub-questions

10.1.1 What is off-site construction and how the benefits relate to the problems of the construction industry in the Netherlands?

Off-site construction is more than moving the creation of 'products' from on-site to off-site. It requires a change in business models, traditional construction paradigms, integration in the supply chain, an anti-cyclical demand and better articulation of demand requirements ahead of time. All these signal that a switch to more off-site products will require a profound and transformational change in the construction industry. The current production model of the construction industry has several bottlenecks, which if unattended, could cause a systematic under-supply of built environment products. Therefore we see that the adoption of off-site construction could lead to more streamlined supply chains, multi-project learning, less reliance on a flexible workforce, less waste and better alignment between sustainability concerns and production methods. Moreover, the construction industry will face stronger competition from actors that will be interested in supplying the Dutch market, which might prove efficient for society but detrimental to the industry.

10.1.2 What type of innovation is off-site construction?

Off-site construction as innovation is new to the firm, radical, high-tech, and both process and product. If off-site is to be adopted, multiple stakeholders, practices, routines, institutions (rules) should be addressed. Moreover, the implementation of off-site construction will require that new services and client-supplier relationships are created and re-designed to ensure that the client experience is improved. The commitment must be comprehensive and profound, coordination and intervention might be needed if a successful transition is expected.

10.1.3 What actions can states take to support and improve innovation?

Strategic niche management, transformational change and system of innovation approaches were combined to produce a list of eighteen activities that need to be supported when the aim is large socio-technical change. The use of different innovation policies can improve the functionality of these activities. However, change must come from multiple sources, and multi-level commitment should be looked for if streamlined transitions are expected. Based on the rationale provided by Weber and Rohracher (2012), we argue that different approaches might be combined if they aim to address different failures. The policy mix can be a complement of multiple goals, rationales and interventions, that need to be calibrated and improved based on feedback loops in the process of implementation.

10.1.4 What roles and instruments can be used to incentivize innovation in the construction industry?

The literature presents with 13 theoretical roles that the government can assume in the transformation process. These are observer, warner, mitigator, opportunities, facilitator, lead-user, enabler of societal engagement, gatekeeper, promoter, moderators, initiator, guarantor and watchdog. At the same time, under these roles, the government might aim at support in different ways the activities described to be key to the process of innovation.

10.1.5 What is the current state of the construction socio-technical system in the Netherlands?

At the system level, we have identified six failures that inhibit the adoption of construction innovations. First, the construction industry depends on cycles to balance their operations. The asymmetry in information between consumers, clients and suppliers has created an industry that is flexible at best and survivalist at worst. Second, because products in the built environment are exposed to the world, keeping innovations protected from 'copycats' creates a challenge in the willingness to invest.

Third, actors work in loosely coupled networks. The project nature of construction projects inhibits the possibilities to collaborate and learn. Each project in the built environment is seen as a unique product. Typical tendering and procurement methods create a fragmentation due to the involvement of professional consultants. Forth, reliance on project-based mentality limits the possibilities to coordinate and create learning mechanisms. Organizations 'lock-in' in traditional practices and multi-project improvement is hardly achieved.

Fifth, the lack of leadership and past problems of the construction industry has created mistrust in the ability of the construction industry to provide high-quality products at fair prices. Moreover, long term needs are fragmented and poorly articulated. Lastly, on the demand side projects are commissioned on the lowest price as a misinterpretation of best value, which lead the competition to be on price and not quality.

10.1.6 What are the main barriers in the adoption process of off-site construction?

Through interviews among lead or potential user of off-site products, we have discovered 15 demand-sided and 10 supply-sided barriers in the adoption process of off-site construction. These barriers were classified based on the 18 key activities presented in the third chapter of this research project.

10.1.7 What can we learn from past global experiences and the current push for more off-site construction in the UK?

Off-site construction was used in the past, with different purposes and goals. The purposes and goals have either harmed the long term prospects of off-site construction or helped the industries to succeed and embed within their respective construction industries. An example of a country that has recently been involved in pushing the use of more off-site construction is the UK. The UK has again returned to off-site construction after they failed the past. The need for off-site construction comes from profoundly rooted system failures that if unaddressed, could affect the long term quality of infrastructure in the UK. This push for the use of modern methods of construction provides interesting insights about instruments that can be used in the Netherlands. We believe that the Netherlands should look for local alternatives to the levers of the construction sector deal, the presumption in favour, knowledge sharing and procuring for value.

10.1.8 How can the national and local government incentivize the uptake of off-site construction?

We provided 15 recommendations for the central government via its different organizations that could help incentivize the adoption process of off-site construction products. Moreover, we have provided recommendations that should help the long term health of the construction industry and improve the possibilities to fulfil its social role. Additionally, we have provided six recommendations that could be implemented at the Municipality level aimed at creating markets for off-site construction products.

From the recommendations presented, six of the recommendations could be implemented to improve the general innovativeness of the construction industry and to help in the adoption of offsite construction; five recommendations could be used to incentivize offsite construction as a technology in the construction industry, and; ten recommendation should help improve the adoption of offsite construction while also helping in the delivery and provision of housing.

10.2 Answering the main research question

We have started this research by asking:

"How can public policy instruments at national and local levels help to overcome the barriers for adoption of off-site manufacturing in the construction industry of the Netherlands?"

This question was formulated primarily to determine the role that public organizations have or do not have in incentivizing the uptake of off-site construction. At the national government level, we have identified seven roles that the government could assume in the process of change required to improve the uptake of off-site construction. These roles are:

10.2.1 National government

Promotor: because of the large scale and commitment required to change old construction paradigms and practices, the government should act as a promotor of a consistent discourse that links the transformation of the construction industry with grand challenges and the fulfilment of societal needs. The government will have to work along different groups to articulate the future demand, create a sense of urgency among the demand and supply chain. Furthermore should promote the nurturing process of current off-site manufactures. Additionally, the government should ensure that these actors are involved in the relevant discussion and learning arenas.

The government should also commission research to determine new business models that link the current capabilities of large construction industry actors and the process of off-site construction. Additionally, a better understanding of value is needed, so selection procedures are based on the best overall value and not rely on the latent fact that best value equals best price.

Moderator: the central government should work in providing a fair arena for discussion of future needs and current capabilities. Moreover, the government should ensure that the discussion process is not used to name and shame, which would further deteriorate the trust in the construction industry, but ensure that different parties state their reasonable expectations of the future and what role they will play on it.

Facilitator: because of the current lack of infrastructure among different organizations, the government should create a business advisory office that provides consultancy and support in organization infrastructure to help smooth the transition between both models. The government should also work to facilitate policies that link the benefits of off-site construction and the limitations caused by environmental laws and commitments.

Additionally, in its role as a facilitator, the government should provide tax incentives to housing associations so they can create long term partnerships with suppliers.

Coordinator of social engagement: the government should commit to long term plans that are multi-party and include different social groups, making clear that change in long-due and urgent leadership and action is needed.

Initiator: the bottleneck of land provision hurts the predictability and articulation of long term demand. The government should review land provision policies to ensure that a clear demand pipeline is created and clear opportunities are delineated for manufactures to scale their production based on future demand.

Additionally, the government should initiate a change in the curricula of civil engineers and architects. The introduction of themes like design for manufacture, lean construction and off-site construction planning could help the workforce to adapt at a faster rate.

Guarantor: The government could create markets through the use of subsidies for bundles of products. This form of forward commitment procurement should be based on a framework that provides opportunities for the benefits of offsite construction to be exploited. A possible example that should be further studied is the presumption in favour of off-site construction.

Gate-keeper: we recommend the government to work with the NEM to produce standards and databases for off-site products interfaces. Additionally, the government can introduce quality labels that can be procured in advance by manufacturers to ensure the delivery of high-quality products while at the same time creating a market for off-site products. Moreover, the government should create and implement more comprehensive definitions of value.

The roles identified here are examples of actions that the central government could take to incentivize the adoption of off-site construction practices and products. However, we highlight the importance of providing long term visions and leadership. Moreover, the government should align the long term health and stability of the construction industry to the long term plans and be willing to compromise to achieve the potential of off-site construction fully.

10.2.2 Local-level

Promotors: municipal authorities could act in promoting more cooperation between off-site product suppliers and urban planners. The fact that aesthetic committees are seen as the ultimate consumer of a product should be changed, allowing more flexibility in the articulation of demand requirements and expected functions. Additionally, the municipalities should provide space for exploring possible synergies between off-site construction products and their needs for housing.

Facilitators: municipalities could work in creating 'pre-approved' system of off-site construction permits based on functional requirements. This system would help streamline the time that is required to obtain a permit and would create the demand and market for the commercialization of off-site construction products.

Initiators: municipalities must work in unbundling land provision and manipulation for political purposes. Committing to long term plans in land management could reduce the cyclic nature of the construction industry that is already affected and guided by changes in economic developments.

Warner: municipalities should study their infrastructure through backcasting and forecasting exercise to determine the risk of not being able to fulfil their needs, and consequently formulating long term vision.

Gate-keeper: while adding more obstacles to the process of obtaining a permit could be seen as detrimental for the construction industry, there is a need to include negative externalities caused by the development and renewal of built environment products. Moreover, off-site construction products should be better at reducing these negative externalities providing benefits for the municipalities and its constituents.

As in the case of the central government, the roles proposed here are examples of actions that could help to reduce uncertainty and improve the uptake of off-site construction. We highlight the capacity of Municipalities to create markets for off-site products. Moreover, municipalities could play a large role in the transformation of the construction industry, however, they currently work as inhibitors of the technology. In other words, municipalities should also be willing to adapt and change their current practices and their vision of projects.

11 Discussion

In this section, we will discuss the scientific and societal relevance of the results of this project. We will also discuss the limitations and the impact these have on the results. In the scientific relevance section, we will reflect on the value of this research for the construction industry and public authorities. We will also recommend a research agenda to improve the insights generated throughout this project. In the societal relevance section, we will discuss how different parties in the construction industry can interpret the results of this thesis.

11.1 Scientific Relevance

While off-site construction is commonly studied as an innovation, little research has been conducted on how can public policy help overcome the barrier of off-site construction. Grey literature has tried to explain the actions that should be taken by different actors. Our approach made use of this reports, scientific literature and innovation adoption and diffusion theories to explain how, at the industry and organization level, the change could be perceived and incentivized by multiple actors in the construction industry. We have combined the Multi-level framework with the innovation systems approach to analyze the why the innovation finds difficulties to diffuse at the system level and why firms might be unwilling to risk their short term competitiveness with the radical change that off-site construction represents.

At the moment of this publication, we are facing new challenges, a changing way of living and more uncertainty than we have ever faced. The COVID-19 pandemic will probably change the way we function as societies in the short and long term. However, the real long-lasting economic, social and environmental effects of this new normality are to be determined, and possibly we might not have a clear picture in the upcoming years. While we consider that uncertainty will affect all the aspects of our lives, we also consider that new opportunities will arise. Halman et al. (2008) point out that platform approaches could benefit from the down-turn of the economic cycles because, during these stages, costumers expectations for variety and customization are lowered. Therefore we consider that this crisis could provide a window of opportunity to re-define what is the role of the construction industry in the provision of infrastructure in the long term, and more importantly, how can this role be maximized to ensure the long-term health of the industry and the society.

The scientific relevance of this thesis lies in the perspective used to analyze the problem of incentivizing off-site construction. We propose to consider off-site construction as a change that requires system transformation, and therefore needs to be addressed under a different more comprehensive and holistic lens. While off-site construction has been studied as an innovation, to the best of our knowledge, no previous study has considered off-site construction as a transformational change.

Moreover, by using this approach in combination with the systems of innovation approach, we have made an effort to provide direct recommendations that could help not only improve the conditions for off-site construction to succeed as an innovation, but also for other innovations in the construction industry. Additionally, we aim to provide a starting discussion point on the different roles that the government could have on the adoption of offsite construction. Because of the lack of sufficient empirical data, the recommendations presented here, are intended to exemplify how different roles might answer to different barriers.

11.2 Societal Value

The construction industry provides one of the most vital functions to the society, the provision of infrastructure that allows us to live, move, entertain and develop. The dependency that we have to the construction industry has removed the sense of urgency among different actors to change and progress at the same rhythm that other industries have. Because of this dependency, it is improbable that industry if

unchanged, will suffer in the short term. However, we recognize the value of modernizing the construction industry to be aligned to the challenges of modern times.

Through this research, we have made an exploratory effort to try to understand the reasons why a technology that promises to provide a modernization that is long due still faces challenges. While our aim in this thesis is to advocate for offsite construction as a solution to some of the problems of the construction industry, we recognize that the modern grand challenges will require that the construction industry also improves through other innovations.

Our societal contribution is threefold. First, we have determined what the barriers that affect different actors when opting for traditional construction methods and off-site construction methods are. These barriers present a picture of specific issues that need to be simplified or solved in order to improve the adoption of off-site construction and in some cases, improve the conditions for other innovations.

Second, we proposed to evaluate off-site construction as a transformational change, comparable to the energy transition. If we move away from the idea that off-site construction should be considered as a typical innovation, we see that the level of cooperation, coordination and effort needed cannot be gathered from within, but should be coordinated and incentivized by the inclusion of stakeholders at national, provincial and local levels. Moreover understanding that 'things must be done differently' will require that the real estate business is affected (for new constructions), and for speculative investors to adapt to this new way of doing business.

Third, we have proposed a series of recommendations and actions that public authorities could take to improve the conditions for actors to adopt off-site construction. Because of the scope of this project, the recommendations are not designed to result in specific actions, but to work as principles for public authorities to investigate in-depth what role they could assume in the transformational process.

In summary, the societal relevance of this thesis is that it aims to create a sense of urgency about the changes needed. As we discussed in Chapter 8, off-site construction has been used before as an answer to different historical challenges. Throughout this thesis, we provided an overview of how off-site construction could be an answer to problems and challenges that the construction industry face. Moreover, through recommendations proposed in Chapter 9, we aim to provide possible solutions for problems that technology like off-site construction faces.

11.3 Limitations & future research

We looked into off-site construction from the perspective of transformative change in this thesis. Moreover, we used a combination of other perspectives and rationales for state intervention to produce a framework that aims at providing an inclusive view of activities that governments can take. However, the combination of approaches presents its limitations since rationales for these are not aligned and, although in some cases, they can be complementary, they also contradict each other. While the focus of this thesis is not on studying the theoretical underpinnings and shortcomings of the approaches used, we recognize that a deeper analysis of the rationales for the activities presented might be needed to produce a list of activities that better provide a framework to analyse the problem.

One of the biggest dissonances between approaches arises when we consider that transitional change calls for openness in the solution space and the use of portfolio options. On the other hand, SNM and SI approaches are orientated at simplifying the rules of the game for specific innovations, which limits the design space and locks the interventions into a single technology. In this thesis, we advocate for the use of off-site construction as a solution to multiple problems of the construction industry. However, other technologies could also provide solutions and alternatives to the problems of the construction industry.

While our approach was to analyse the system from a meta-level, we recognize that several technical challenges and barriers could be relevant to the process of adoption of offsite construction. These technical challenges might be better analyzed and simplified by looking at the problem from a technology perspective to improve the interdependencies that could arise from the use of off-site construction and the existing construction model.

This first attempt to explore the actions and roles that national and local authorities could take to incentivize off-site construction remains to be tested in the policy mix. Because policies can work in favour or against each other when introduced, we recommend to test and compare the recommendations presented in this research with existing policies at the national and supranational level. Moreover, because of the large variety in regulations and policies at local levels, we recommend researching the effect of the policy-mix at the level of municipalities.

This research aims to provide insights into the current barriers that affect the adoption and uptake of off-site construction in the Netherlands. Our recommendations were are based on the views of a selected group of actors. While these actors all have an interest or are well-positioned to make use of off-site construction methods, the generalization of their views will be hard to justify. Some studies have been conducted on the perception of stakeholders about platforms approaches to housing (Halman et al., 2008), however, no previous analysis has been conducted on how these perceptions on the limitations in the adoption process of off-site construction could play a role in transformational systems.

This exploratory study conducted interviews on a small group of actors, and a broader more comprehensive study could provide a deeper understanding of the barriers and limitations that construction industry actors face when deciding to supply or adopt off-site construction products. The fact that we have conducted only seven interviews represents a limitation if we aim to generalize the problems here described. Moreover, the limited sample and empirical data collected could be a source of bias.

To counteract this bias, a group of actors that was not interviewed, but should be interviewed in the future, are actors that are against the use of off-site construction. A possible example could be actors that represent project management consultancy companies since it has been argued that they might see their role and relevance in the construction industry reduced if more off-site construction is to be adopted. Moreover, these actors might signal to different barriers and challenges that could play a role and are required to be addressed.

At the same time, it is important to mention that the construction industry is highly fragmented, and that interest and decision-making are equally fragmented. This fragmentation creates a problem for this thesis project since to provide recommendations that are well seen by actors in the industry broader participation and 'democratization' of the empirical data should be carried.

In Chapter 8, we explained some of the recommendations that were made by the government in the UK. However, they are not the only ones, since Sweden, Japan, Malaysia, Singapore, Norway and the US have also either made efforts or are starting to take a more in-depth look into off-site construction. While at the landscape level, cultural factors might differ, the regimes appear to have close similarities and interest in the short term. Therefore, we recommend that a more in-depth look is given to the specific lessons of these countries to determine what has been successful so far.

Different sector organizations, groups and initiatives (see. www.cobouw.nl, ww. www.conceptueelbouwen.nl, www.btic.nu) have started looking into the topic of off-site construction and the possibilities of upscaling the technology. We recommend combining the knowledge acquired through these organizations to create a clearer picture of the interest and lessons learned to determine how could a better more comprehensive network of actors could be established to improve the learning process in the long term.

Additionally, we recommend researching how the current organizational structures and business models of housing associations could be modernized to be aligned with the off-site construction business models.

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Appendix 1

Questionnaire

https://docs.google.com/forms/d/e/1FAIpQLSc5XO6T0AcBbmZsUw6X30bZOiFZGwbRa29KuOCy0_wuajsVXQ/viewform?usp=sf_link

TU Delft - Complex System Engineering and Management

Researcher: Miguel Ortega

Supervisors: (1) Dr Ad Straub; (2) Dr Linda Kamp; (3) Dr Marja Elsinga

Project: *Incentivizing off-site manufacturing in the Netherlands: Understanding the role of public policy in the adoption of off-site manufacturing: A UK's case study, applied to the Netherlands.*

Questionnaire additional information sheet

This questionnaire forms part of a two-step interview process about the adoption barriers of off-site construction. The first step a questionnaire contains general questions about the respondent line of work, responsibilities, awareness of off-site methods and perception of adoption barriers. This introductory questionnaire aims at providing the researcher a guideline into the perceptions of the interviewee, in order to structure an interviewee that allows both parties to dig into the specifics of the challenges and barriers of off-site construction.

The following section describes the questions presented in the questionnaire and tries to provide additional information that might help the respondent answer the questions.

Section 1, general information questions

No.	Question	Possible answers	Explanation
Section 1			
1.1	What is your role (the role of the organization) you identify better in the building/project process? (Please select one or more)	- Manufacturer - Supplier of materials/ components - (Public) Housing provider - (Private) Housing provider - Real Estate Developer - Designer (Architecture & Engineering) - Contractor - Public servant - Representative of labor union - Logistics contractor - Infrastructure provider - Other	The options describe different organizations and/or roles that an actor might play within the off-site construction supply chain. A respondent can select more than one option, indicating the multiplicity of roles that actors take in the construction process. Given that off-site adoption barriers are spread among different actors in both the demand and supply side, the list tries to include as many roles as possible, however, given the fragmented nature of off-site some roles might not be indicated, in which case we ask the respondent to specify if they consider that their role or the role of the organization falls outside of the previously mentioned roles.
1.2	According to Hartmann, et al (2008) construction clients can be classified based on the frequency they build and the sector they operate in. Please indicate which of the following combinations the company/institution	- Public and occasional client - Public and professional client - Private and occasional client - Private and professional client	Hartmann (2008) describes four different types of actors in the construction industry. Two criteria are used: - Frequency of projects (buildings) o Professional client: perform or procure construction works regularly.

	you work for can relate the most.		o Occasional client: building is a unique and infrequent activity. - Sector o Public: institutions that on a national and local level procure construction works to provide public goods. o Private: non-state own entities that demand construction work to produce goods and services for a profit.
1.3	Do you make use of off-site construction methods?	- Yes / no / not sure	Off-site construction is widely used in the industry, however, the awareness of its usage is not clear among actors. Ambiguity plays a large role. Please indicate whether you consider you use off-site products or components in the construction process of the different projects you are involved in.
1.4	Currently, thousands of products are considered to be part of the off-site construction industry? Please scroll through the list and mark as many products you use during the construction phase.	- Framing systems - Volumetric modular buildings - Cladding systems - Bath/toilet/kitchen pods - Building services - Structural Insulated panel systems - Panelised roofing systems - Foundation systems - Other:	The products mentioned here are the more common used off-site products. However, given the large variety and scope of off-site construction you might make use of different products. If so, please indicate under the 'Other:' section.

Section 2

The barriers mentioned here are a recollection of 'generic' barriers around the world. Twelve studies were used and up to 46 barriers were discovered, in order to avoid presenting this large number of barriers these were reduced to the ones presented below. If you consider that there are additional relevant barriers please use the last questions to express what issues are of your concern.

All questions in this section can be answered using a 'likert' scale. The scale runs from 1 to 5, 1 being a perception that the barrier is irrelevant to the context of the Netherlands and 5 being a perception that the barrier is highly relevant.

2.1	Lack of certainty about the role of stakeholders and partners.	Stakeholders in the building process might consider that implementing off-site construction in their projects is not feasible because they cannot identify what role they could play in the new process.
2.2	Conflicting/missing regulations	Regulations play a large role in the design and approval process, off-site can clash or be outside of scope of current regulations.
2.3	Uncertainty about performance	The benefits of off-site construction are not clear, therefore investing into new technologies or adopting them can be a risk.
2.4	Conflicting information about components	Technical information about products/ components is missing or not clear.

2.5	Increased need for integration of stakeholders early in the process	Inter-organizational need for change in the supply change, especially in the early process, which, is in conflict regular practices of the construction industry.
2.6	Design freeze limitations (Implementing off-site techniques might require that the design of the building is 'frozen' early in the project)	Impossibility to implement changes in the design of the project in late stages.
2.7	Lack of organizational infrastructure	There is no established organizational processes, skills, knowledge and culture to adapt to the requirements of conducting off-site construction projects.
2.8	Insufficient benefits v. associated risk	Off-site in its current form cannot justify additional risk. Current business model offers enough incentives not to change (stable profit margin), therefore, adapting off-site represents an additional risk.
2.9	Lack of time/resources needed to integrate stakeholders early in the process	The process requires too much coordination, the organization is not ready and/or willing to perform the coordinator/ manager of the process, especially in early stages when there is no full certainty about project's feasibility.
2.10	A poor or negative image of off-site construction methods	Off-site is commonly seen as a poor-quality product. The adoption of off-site can lower the quality of the existing stock of properties.
2.11	Lack of flexibility and adaptability in the late project stages	Wet construction offers more possibilities to change in late project stage. Current practices fit better with this model.
2.12	Higher initial cost	Off-site methods represent a greater investment when compare to traditional investments.
2.13	A higher level of complexity (throughout the process)	Organizational changes along with a greater need for cooperation increase uncertainty and complexity, adoption of off-site represents too much of an organizational challenge.
2.14	Lack of proven products (e.g. examples of projects that have proven successful)	Off-site construction is not a proven method, there is not enough practical examples of successful projects.
2.15	Higher risk due to the lack of information	Uncertainty about products and processes represent a risk too high to allow for a project to be feasible.
2.16	Other:	Please write down any barrier that you consider relevant and is not mentioned above.

Interview protocol (example)

Subject: Stijn Daniels, The Student Hotel

Date June the 5th, 2020.

Title: perception of off-site manufacturing construction methods barriers of adoption.

Introductory statement,

You are being invited to participate in a research study titled **Incentivizing off-site manufacturing in the Netherlands: Understanding the role of public policy in the adoption of off-site manufacturing: A UK's case study, applied to the Netherlands.**. This study is being done by **Miguel Ortega and supervised by Dr Ad Straub, Dr Linda Kamp and Dr Marja Elsinga** from the TU Delft.

The purpose of this research study is **to understand in depth your perception of the barriers of off-site construction in the Netherlands** and will take you approximately **60** minutes to complete. The data will be used for the design of a policy note.

Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any question.

1. Explain research objectives
   - Determine actions to be followed by public actors to incentivize the wider use off-site construction in the Netherlands.
   - Compare the use of public policy instruments in the Netherlands and the UK in the construction industry.
   - Establish what factors and barriers are more relevant and hinder the adoption of off-site manufacturing.
2. Explain the Interview objectives
   - There is a large pool of research about challenges and barriers of off-site in many countries like the UK, Sweden, Australia, Malaysia, China, etc. However, it is not as clear when we talk about the Netherlands, therefore when we talk about a centralized effort (e.g. by the government), it might be important to know what are the specific challenges to the country in question.
   - Since these barriers are generic, it is hard to see how, they affect the specific construction industry in the Netherlands, specially in areas such as: organizational culture and risk perception, associated benefits. Therefore it is important to determine in depth not only if barriers are relevant but why they are relevant.

3. Explain the interview structure
   - So you already answer the questionnaire, which was used as a way to study what are the relevant barriers in your position. This is step 1.
   - Step 2 consist on the following interview, which is structured around the answers you provided us in the questionnaire. Many questions try to challenge the perception and ask the why of point of view. The reasons to do it this way is to be able to understand in depth the reasons behind an specific barrier.
   - Finally we have prepared some questions about the role of public institutions, and how they are perceived in terms of innovation drivers or barriers.
4. You work for an organization that could be classified as build-to-rent, or buy-to-rent, these organizations have an special position since they are both actors in the demand side and the supply side, do you think that these type or organizations are better positioned to adopt innovation?
5. At the same time your risk profile is different from other organizations, since the integration of demand and supply makes investors especially susceptible to specific risk. Do you consider that having integrated demand-supply affects your risk tolerance to innovation?
6. The following questions are based on the responses you provided in the questionnaire.

Answers:

No.	Question	Imp.	Follow up question
2.1	Lack of certainty about the role of stakeholders and partners.	1	
2.2	Conflicting/missing regulations	2	
2.3	Uncertainty about performance	2	
2.4	Conflicting information about components	2	
2.5	Increased need for integration of stakeholders early in the process	4	It is clear that the construction industry is highly fragmented. This fragmentation and the business models of different contractors makes it hard to integrate them into one single decision-making chain required effectively implement off-site. Could you please indicate what has worked and what not in previous instances where you had to integrate stakeholders?
2.6	Design freeze limitations (Implementing off-site techniques might require that the design of the building is 'frozen' early in the project)	4	Is it design freeze a cultural problem, where stakeholders are used to modifying requirements as per go basis. Or is it design freeze a problem because market conditions usually signal that new requirements arise after the inception of the project? Or is design freeze more relevant for some other reason?
2.7	Lack of organizational infrastructure	4	Do you think that organization infrastructure plays a role because the require personnel and expertise to move processes from on-site to off-site is missing? Is it therefore a shortage of skills?
2.8	Insufficient benefits v. associated risk	5	Off-site proponents tend to point out that the benefits could solve some of the problems of construction industry, and therefore their acceptance and implementation would provide widespread benefits. However construction actors seem to be comfortable with how their business works, do you consider that the tradeoff relates for example to the 'volunteer's dilemma (where actors see themselves in the position to change, but lack the incentives since the risk pool is too uncertain)? Or do you think that the trade-off relates more to the fact that the construction market is highly volatile and therefore the perception that the black swan is always around the corner plays a role? Or is there an additional risk (e.g. investors aversion to risk, stakeholders misunderstanding of the benefits)
2.9	Lack of time/resources needed to integrate stakeholders early in the process	4	Is this a problem that you see specifically in the organization you work for? Some studies have proven that off-site uses similar resources in comparison to on-site, however the distribution of resources is usually heavier at the beginning for off-site? Do you think that financing mechanism play a role?
2.10	A poor or negative image of off-site construction methods	4	Do you have any particular example of success or failure? A lot has been discussed about Ronan Point in England and the Million House Programme in Sweeden, do this ring a bell? I understand the in the Netherlands there are some actors that work with off-site methods but provide really low quality, could you say that you anchor your perception to these companies?

2.11	Lack of flexibility and adaptability in the late project stages	2	This relates to the design-freeze problem, why is it that design freeze is much more relevant that the lack of flexibility?
2.12	Higher initial cost	5	This is an area of concern for many actors in the construction industry, specially actors in the demand side, a lot of research has been done about the potential of off-site to reduce cost in the long term. You operate the buildings you develop, how much does this plays a role when evaluating the cost of off-site? Financially, a shorter construction time usually relates to lower interest and less opportunity cost, together with less risk, do this play a role?
2.13	A higher level of complexity (throughout the process)	5	Where do you see an spike in complexity? Perhaps building permits, financial requirements, stakeholder integration, on-site works? Or other?
2.14	Lack of proven products (e.g. examples of projects that have proven successful)	2	
2.15	Higher risk due to the lack of information	2	Do you think that if off-site manufacturers where more explicit about the supply chain cost of the implementation of off-site would you see this as a lower risk? A national database? Certifications?
2.16	Other: Big difference in feasibility of prefab per country		this do you refer to the fact that there is not enough literature specific to the Netherlands to support a move towards off-site? In what sense, does it relates to building permits, cost, risk profiles? How relevant do you think that not having the right tools to evaluate projects affects the feasibility? Or is it that the Netherlands as a country culturally is not the right fit for off-site?

7. Something that was not discussed in the questionnaire is the role of public institutions, do you see public institutions as drivers of innovation? Do you consider their participation as active? Economist justify the intervention of governments when there are market failures, like lack of productivity, under supply or asymmetric information, is it your perspective that public institutions should limit their involvement in markets when there are externalities? Do you see the under-supply as an externality, the low productivity?
8. Land provision is often mentioned as a barrier for the implementation of off-site, do you consider it to be specific to off-site, or would you say that is in general a barrier in the provision of housing? If yes, why is it specific to off-site?

Concluding remarks.

So this is the end of the questions I prepared. Is there anything you will like to add?

Final thanks,

It goes without saying that your support and interest in our research is highly valuable to our discoveries. We appreciate the time and knowledge that you have just shared with us. We understand that some of this information might be considered sensitive and/or confidential, therefore, we commit to make sure that none of the information provided will be used with purposes outside of the boundaries of this research.

Again thank you for the time and shared knowledge. I would be glad to share a summary of the results when the project is over.