Article

Modernizing the Dutch Housing Industry using offsite construction:

Removing adoption barriers through innovation policy

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ABSTRACT

The construction industry plays an essential role in the provision of infrastructure and particularly housing. At the same time, because of its size and participation in the national economies, the improvement of the construction industry could generate long-lasting benefits for the society. However, the construction industry has failed to adapt to modern societal and technological challenges. Offsite construction is being proposed as a solution to some of the structural failures that inhibit change and adaptation of the construction industry. Even though offsite construction has been long considered as a solution, its uptake remains low. Public authorities can play a large role in incentivizing offsite construction through public policy and as major clients of built environment products. In this research, we intend to answer the question of: *How can public policy instruments at national and local levels help to overcome the barriers for adoption of offsite manufacturing in the construction industry of the Netherlands?".* An exploratory case study of the conditions in the Netherlands was used to determine adoption barriers and possible roles that public authorities could have in incentivizing offsite construction. We found five barriers that affect the prospect of adoption of offsite construction but also affect the general innovativeness of the construction industry, and fifteen barriers that are offsite construction technology-specific. Based on key activities derived from innovations systems and transformational approaches to innovation policy, we proposed different roles that the government could assume in the process of incentivizing the adoption of offsite construction. Six possible roles and instruments were proposed to improve the innovativeness of the construction industry; Five possible roles and instruments to improve the adoption and uptake of offsite construction and; ten roles to improve the uptake of offsite construction and the provision of housing.

1 Introduction

When compared to other industries like retail and manufacturing, the construction industry (CI) is considered as an industry with a low innovation rate (Farmer, 2016, Winch, 2003). A low innovation rate is usually associated with low productivity growth. Because of the participation and role that the CI has on the economy and the wellbeing of the society, the low productivity growth has become of particular interest for policymakers. Moreover, further developments could magnify the effects of low productivity and create systematic failures that would lead to the under-provision of infrastructure. Offsite construction is considered as a solution to the some of the structural failures of the CI (Build Offsite, 2018, de Laubier et al., 2019, Nadim and Goulding Jack, 2011). However, and even though offsite construction, or variations of it, have been around since the 19th century, its adoption and widespread use has only been mainstreaming as an efficient construction method in the period after the Second World War.

Offsite construction is the process of prefabricating elements offsite so that they can be later assembled on-site (O'Connor et al., 2014). In some countries like Japan and Sweden, it is widely used (Koebel et al., 2004). In other countries like the U.K., Australia, Singapore and Hong Kong, governments are pushing the CI to adopt this technology (Burgess et al., 2018). In the Netherlands, the use of precast concrete elements was widely used in the rebuilding process following WWII (Pries and Dorée, 2005). However, the smaller scale and type of the projects needed once the rebuilding process was over gave way to the use of stacking (bricks) methods (Pries and Dorée, 2005). Recently the use of offsite construction technologies is gaining traction among different actors in the CI 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., 2008a).

The recent interest in offsite construction comes as an answer to the need to build and refurbish affordable homes at a large scale in the upcoming years to cover future demand (Jongeneel, 2018). However, it is not clear if the current industry is capable of delivering the expected results, especially at affordable levels, while maintaining a healthy profit margin (Burgess et al., 2018). Moreover, because of the strong dependence on the services that the society has on products from the CI, the demand-driven market and the exploitation focus of the CI voluntary change seems unlikely (Farmer, 2016, Eriksson et al., 2014, Faber and Hoppe, 2013).

This change and the introduction of new construction methods in the industry will probably require strong and wide cooperation and commitment from actors in the chain of supply (O'Connor et al., 2014). The state can play a role in this process of change in the CI, not only because it can use public policy to incentivize innovation but also because they represent the largest client to the CI (Halman et al., 2008a, Lenderink et al., 2019). 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).

While some interest groups and sector organizations (BTIC, AEDES, Bouwcampus, Netwerk conceptueel bouwen, among others) have started to look for solutions on how to speed up the uptake of offsite construction, no research has been published on how the government can participate and incentivize the adoption of offsite construction in the Dutch CI. Therefore, in this article, we aim to answer the question *"How can public policy instruments at national and local levels help to overcome the barriers for adoption of offsite manufacturing in the construction industry of the Netherlands?".* To that end, we intend to discover (1) The role of public authorities in incentivizing offsite construction. (2) The adoption barriers that impede the uptake of offsite construction among actors in the CI.

Section 2 describes what is offsite construction and why it is needed. Section 3 digs from an innovation perspective what influences the adoption and diffusion of innovations, and what approaches we can use to analyze the system and promote innovation. Next, in section 4, we describe the methodology of this study. In section 5, we present what, in the Dutch construction industry, are the barriers that inhibit the adoption of offsite construction. In section 6, we recommend actions that the government can take to incentive the adoption of offsite construction. Finally, in section 7, we conclude and discuss the value of this publication.

2 Offsite construction in a nutshell

2.1 What is offsite construction?

Offsite construction is the process of prefabricating elements offsite then transported and assembled on-site (O'Connor et al., 2014). However, this goes against the standard and current practices of 'traditional' on-site construction projects. Offsite 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). This change involves the restructuring of relationships in the supply chain, the development of new products, the coordination of regulation that better suits the nature of offsite and several other factors that are interrelated and interdependent (Goulding and Arif, 2013). The Housing Forum (2004) is empathic regarding the change that is required to implement offsite construction, claiming that "*[the organization] ... has to be prepared to do things differently".*

Among offsite construction products, we find elements that can be as complicated as modules with the size and fixtures of one or several rooms, or simpler elements like prefabricated concrete elements. In basic terms, the types of offsite construction can be characterized based on the level of prefabrication they have (O'Connor et al., 2014). Volumetric or modular systems are products that have a higher level of completion. On the other end of the spectrum, we have components, that are non-structural elements, usually for electrical or mechanical services.

Offsite, in innovation terms, represents a deviation from traditional construction in the sense that it involves a new process of delivery, a new product and a new way of production in the CI. Moreover, when compared to the current CI, it represents a high tech innovation, that involves the radical restructuring of social and business constructs, along with processes and a large change in the 'classical' paradigms of the CI (Winch, 2003). Moreover, offsite construction also represents a service innovation, meaning that the implementation of offsite construction will lead to relationships between suppliers and clients to be redesigned and restructured to cater for the emerging needs of clients(Flikkema et al., 2007). If offsite is to be adopted, multiple stakeholders, practices, routines, institutions (rules) should be addressed. The commitment must be wide and deep, coordination and intervention might be needed if a successful transition is expected.

2.2 Offsite construction benefits

Much focus has been put into understanding what could be the advantages of offsite construction (Goodier and Gibb, 2005), these advantages or benefits are seen as answers to many of the issues that the CI has (Lessing et al., 2005). At the same time, 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).

Among the most relevant benefits of offsite construction, we find a decrease in construction time, increased quality, more consistent products, fewer defects, increase value, higher sustainability, reduced initial and lifecycle cost, less waste and others (Burke and Miller, 1998, Ferdous et al., 2019, Li et al., 2014, Lu and Korman, 2010). Despite of these benefits, the large effort in changing the industry to work in ways that are substantially different from their current practices requires that the motivations are equally urgent and relevant. Therefore, we shall look into the need for offsite construction next.

2.3 Why do we need offsite construction?

The CI has been for long catalogued as an industry with low productivity growth (Barlow, 1999, Halman et al., 2008a, Farmer, 2016). 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 that will risk their ability 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 CI faces structural problems that limit its ability to fulfil its societal function (Boelhouwer, 2019). The problems that the CI faces are, among others, slow response to demand signals and requirements, rising construction cost that affect affordability, low-profit margins, underinvestment in innovation, declining infrastructure quality, rising sustainability concerns and insufficient capacity (Halman et al., 2008b).

An ageing population and access to labour play a big role in the capacity of the CI to deliver projects (European Comission, 2018). These challenges create a bottleneck, that combined with the strong dependence that the society has with the providers of infrastructure causes prices to rise. Because of Brexit, we expect that accessing labour would not be an immediate issue. Because of the strong economic performance in the Netherlands, it is expected that much of this workforce will try to look for work opportunities here. This development 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 CI will not be able to keep up the pace of the demand, causing construction prices to remain high. Because offsite construction is less reliant on project-dependent workers since most are moved to factories, better predictability about labour requirements can be achieved (Goodier and Gibb, 2005).

One of the main concerns of the CI 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 offsite construction will probably still compete in the price arena, labour and stakeholders can be better integrated into the supply chain, allowing 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 special importance since the CI is one of the bigger 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 has done many projects to become unfeasible or more expensive. Offsite construction relies less on heavy machinery, and the manufacturing of products is done under controlled environments where emissions are more easily controlled. Furthermore, because offsite construction is produced under manufacturing conditions, there is a better use of raw materials. In contrast, the CI is one of the biggest producers of waste (Li et al., 2014).

We have argued that offsite represents a radical change from the current practices of the CI. 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 with policymakers (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. Nevertheless, each technology represents a new set of challenges and context-dependent variables that affect their possible adoption (Borrás and Edquist, 2013).

3 How to influence the innovation process?

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).

3.1 Rationale for State intervention

Innovation policy has been justified based on the perspectives that economist and policymakers have on the role and importance of public intervention for the process of innovation (Sexton and Lu, 2012, Edler and Fagerberg, 2017). Classically two main streams explain the rationale for innovation policy (Edler and Fagerberg, 2017). Market failure and innovation-systems (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.

3.1.1 Market failure approach

After WWII and seen the success of the investments made by the U.S. and U.K. governments, several academics argued that investment in the creation of knowledge for innovation should not be limited to warfare but should have a broader perspective and approach (Edler and Fagerberg, 2017). However, the rewards of investing in the creation of knowledge could only be partially extracted by market parties and in many cases, its

large social impact that was underutilized. This underutilization brought the perspective that there were market failures, and therefore intervention was needed in order to incentivize innovation (Edler and Fagerberg, 2017).

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 the actual implementation of it (Mazzucato, 2016). Mazzucato (2016), acknowledges this limitation 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.

3.1.2 Innovation systems approach

Building on the idea that innovation should be promoted and developed, but with the realization that solving market failures were not enough many scholars brought forward the idea that policy should play a larger role in making economies more dynamic and competitive (vis-à-vis other nations) (Edler and Fagerberg, 2017, Schot and Steinmueller, 2018). The 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 the innovation systems led to the development of the National innovation system approach. The National innovation systems explain 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 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).

Edquist (2011) defines ten core activities or functions that should be addressed to allow innovation to take place. These function are: creation of knowledge to provide alternatives to incumbent technologies; competence building among organizations to allow learning and adaptation of the created alternatives; the formation of new markets to ensure that ideas and innovations can be diffused; articulation of requirements to steer the solution space to provide effective alternatives to problems; forming and changing organizations to simplify and allow further development of alternatives within the a new or modified set of 'rules of the game'; integrating new knowledge into current systems through networks that allow the diffusion of new alternatives; forming, changing and adapting formal institutions like laws or regulations to promote dynamism in the systems; providing incubation space so alternatives can experiment and develop within protected spaces; providing financing for innovations that are not able to receive the level of funding through market mechanisms and; creating and supporting consultancy services to allow provide temporal competences for firms in order to reduce 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.

3.1.3 Transformation systems 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 (MLP) 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).

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 interaction. The perspective 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, that is considered the development space; regimes or the incumbent socio-technical system, and; landscapes, that is considered the embedded developments of the system (Geels, 2004).

The MLP approach argues that the innovation process follows a general pattern where developments at the landscape level provide incentives for technologies at the niche level to gain momentum and become mature enough while affecting the stability of the regime and opening windows of

opportunity for technological innovation to root itself within the regime (Geels and Schot, 2007). While this approach recognizes that forces at the landscape level provide the destabilizing forces that open windows of opportunity, it also recognizes that because of the urgency of the societal challenges of the 21st-century policymakers should focus on the designing policies aimed at nurturing niche innovations and changing or transforming and debilitating socio-technical regimes (Kivimaa and Kern, 2016).

Within the systems transformation approach, two main sub-approaches have been developed, strategic niche management and transition management (Geels, 2004). Similarly to the case of systems innovations, several processes and activities have been formulated that should be addressed in order to facilitate and support socio-technical change. The strategic niche management (SNM) approach calls for the articulation of long term expectations and vision within the nurtured technologies; the building of networks for long term goals that align the benefits of the nurtured technology with the long term needs of the society and; facilitating learning processes that transfer first-order knowledge to second-order knowledge (training and education) (Schot and Geels, 2008).

Transition management argues that stronger, more strategic forms of governance are needed (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. Moreover, and in a similar vein to SI and SNM, this approach calls for the solving of steering problems through different activities, which are: coordination of discourse, to ensure that long term interest is expressed in a coordinate and aligned way; definition of long term goals that allow feedback learning loops ensuring flexible and responsive management of the transition process; forecasting and backcasting the system objectives in order to discover paths, setting long term goals and identifying alternatives; management of portfolio options to avoid lock-in and escalation of commitment, and; the development of transition arenas that are not politically motivated.

3.2 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 a 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.

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 (information asymmetries, knowledge spill-over, externalisation of cost, over-exploitation of commons), structural systems (infrastructural failures, institutional failures, interaction or network failures, capability failure) and transformative (directionality failure, demand coordination failure, policy coordination failure, reflexivity failure) failures in order to address the innovation process holistically.

The approaches presented above are derived from the need from these different rationales and needs. Moreover, they answer to different failures and might provide better insights into what is needed to achieve the objective and goals of policy. We consider that because of the scale and type of change that is required to adopt offsite construction we should consider these activities as a set of tools that work at removing failures and barriers for technology and innovation adoption and diffusion (see table 1).

Public policy instruments to incentivize innovation have been studied by multiple authors (Edler, 2016, Borrás and Edquist, 2013, Kivimaa and Kern, 2016). Edler (2016) reviews fifteen ‘common’ instruments used by policymakers and classifies them based on their objective. Similarly, Kivimaa and Kern (2016) classify instrument based on their use in the context of SI and TM.

3.3 The governance of change

The role of the state in innovation has evolved in line with the approaches of market failure, systems of innovation and transformative change. Originally, 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. Borrás and Edler (2020) argue that in the process of socio-technical transformation and change the state can play 13 different roles, that are: observer, warner, mitigator, opportunist, facilitator, lead-user, enable of social engagement, gate-keeper, promoter moderator.

Table 1 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	Systems of innovation	Creation of new knowledge
			Competence building
	Over-exploitation of commons		Formation of new markets
	Externalization of cost		Articulation of requirements
	Knowledge spill-over		Forming and changing organizations
			Integrating new knowledge into current systems
Structural systems failures	Infrastructural failure		Forming, changing and adapting formal institutions
	Capabilities failure		Providing incubation activities
	Institutional failures		Providing financing for innovations
	Interaction or network failure		Creating and supporting consultancy services
Transformational failures	Directionality failure	Strategic Niche Management	Articulation of expectation and visions
			The building of social networks for long term goals
	Demand articulation failure		Learning processes
	Policy coordination failure	Transition management	Coordination of discourse
			Definition of long-term vision and goals
	Reflexivity failure		Forecasting and backcasting of system
			Management of portfolio options
			Development of transition arenas

4 Method

We will conduct this research using an *exploratory case study* approach. The case study will be based on the perception of different actors in the CI about the barriers and challenges of adopting offsite construction. We aim to consolidate the fragmented and varied perspectives of actors in the CI.

4.1 Data collection

In order to determine the state of the CI 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: *Offsite construction, Dutch CI, CI innovation, sustainable innovation, CI change,* in combination with the Boolean operator *AND*.

The second part of the empirical data collection is to determine adoption barriers in the Netherlands. To study how these barriers are perceived among different stakeholders in the Netherlands interviews where be conducted. Actors were selected based on their suitability to adopt offsite 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 offsite barriers in the context of the Netherlands. The information was later triangulated with the findings of the literature review.

In total, seven interviews were conducted among different actors in the CI. Among the interviewees, four indicated that they had more than one role, three indicated that they had only one role. Their roles were public servant, contractor and designer. Among the others they indicated that the organizations they worked for did Real Estate and Development (3), contractor (2), asset management (2) and design (1).

4.2 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 can provide in-depth knowledge about a topic. However, published literature might not be enough, and grey literature might result in a good, although probably biased, source of information. Because of the relevance of the CI in society and its large market power, many umbrella organizations publish reports that aim to provide the views of its members. Therefore, this source of information should be 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 good instruments to collect in-depth knowledge about a topic and can provide greater insights than expected. Nevertheless, interviews are hard to achieve, and might not always be available. To overcome this, a careful study of the interviewees' trajectory and relevance to the topic being study is needed. Another limitation is that even if the interviews are correctly selected, they do not hold the answers that we might be looking for. There is no assurance that the interviewee will have deep knowledge of the topic that is being studied, or under the focus that the author is studying it. This, along with time constraints, presents a hazard for the completion of the research project. Moreover, there is limited empiric data, and the sample size of actors might not reflect the general views and interest of different groups in the CI.

5 Results: The socio-technical system and offsite adoption barriers

5.1 Adoption barriers of offsite construction

So far, we have focused on the advantages of offsite construction and why it should be adopted in the face of modern societal challenges, however, as we mentioned, initial offsite construction has faced some resistance. This resistance is partly due to the socio-economic context of the CI but also because of specific barriers that make its adoption difficult. These barriers of offsite 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 offsite construction (Hwang et al., 2018).

We have compiled a list of barriers from literature. 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). A total of 46 barriers were identified. From these 46 barriers, 20 were confirmed by interviews, and two more specifics for the Dutch CI were also discovered. We also identified 2 more barriers that are specific to the Dutch construction industry. Table 2, summarizes

Table 2 Offsite construction Barriers

Barrier	Barlow	Goodier & Gibb	Pan, et al.	Nadin & Goulding	Pan & Sidwell	Larson, et al.	O'Connor, et al.	Steinhart, et al.	Choi, et al.	Hwuang, et al.	Hu, et al.	Ferdous, et al.
	1999	2005	2007	2010	2011	2013	2014	2015	2017	2018	2019	2019
Higher initial cost	x	x	x	x	x	x	x		x	x	x	x
Lack of 'proven' products in the market		x	x	x	x	x		x	x		x	x
Lack of culture of 'design freeze"	x		x	x		x	x		x	x	x	
Client resistance	x	x	x				x		x	x	x	x
Lack of certainty in role of stakeholders	x		x	x		x	x		x	x		
Conflicting/ missing regulation		x		x		x			x	x	x	x
High level of logistical cost			x	x		x	x		x	x		x
Lack of organizational infrastructure		x	x		x		x		x	x	x	
Increase levels of planning activities	x	x	x	x		x	x			x		
Negative image	x	x	x				x		x		x	x
High level of complexity in planning and executing process	x	x		x			x		x	x	x	
Integration of stakeholders			x	x		x	x		x	x		
Lack of flexibility and adaptability	x			x		x	x			x	x	
Insufficient benefits v. associated risk		x	x	x	x	x					x	
Conflicting information about components/systems	x	x		x		x					x	
Lack of understanding of the benefits of offsite		x					x			x	x	x
Too large change in construction paradigms			x			x	x		x			
Public procurement practices						x			x			
Lack of leadertship											x	x
Land provision and access	x		x									
Mismatch between investors demands and the nature of the construction industry	x			x		x					x	x
Ability to fit consumer expectations (architects)												
Aesthetics and prodcut flexibility												

5.2 Innovation barriers for offsite construction and the innovativeness of the construction industry

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 offsite construction.

Barriers that impact the general innovativeness of the construction industry and the adoption of offsite 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.

Barriers that relate to the specific challenge of adopting offsite 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 offsite 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.

5.3 Offsite construction adoption barriers transformative change

The adoption barriers of offsite construction provide us with an idea of why it is difficult to change or adapt to new technology. On the other hand, as we discussed in section 3, certain functions should be supported to improve the conditions for innovation to develop successfully. Innovation barriers are problems that affect the key activities of transformation and innovation systems presented in Table 1. From the 22 barriers found through interviews and the analysis of the construction industry, we will make use of 19 barriers. 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.

Table 3 Barriers that affect key activities in innovation systems (Schot and Geels, 2008, Edquist, 2011, Kemp et al., 2007a)

	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	Fragmentation of supply-side actors
	Learning processes	Lack of organizational infrastructure	Lack of organizational infrastructure
Transition management	**Definition of long-term vision and goals**		Mismatch between investors demands and the nature of the construction industry (high capital investment)
	Forecasting and back casting of system	Insufficient benefits v. associated risk (Chicken or egg dilemma)	
	Development of transition arenas	Land provision (articulation of demand)	
Development of 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	**Integrating new knowledge into current systems**	A poor or negative image of offsite construction methods Higher risk due to the lack of information	
	Forming, changing, and adapting formal institutions	Procurement practices	Conflicting/missing regulations. Increase 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	

6 The role of government in removing barriers and incentivizing the adoption of offsite construction

Based on the activities proposed in Section 3.2, we have designed recommendations for the role that public authorities can take when incentivizing offsite construction. First, we look at the recommendations at the central government level and then we will review the roles of the government at the local (provincial and municipal) level.

6.1 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 CI 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 offsite 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 CI actors and the process of offsite 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 CI, 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 offsite 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 offsite 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 offsite construction.

Gate-keeper: we recommend the government to work with the NEM to produce standards and databases for offsite 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 offsite products. Moreover, the government should create and implement more comprehensive definitions of value.

6.2 Municipal level

Promotors: municipal authorities could act in promoting more cooperation between offsite 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 offsite construction products and their needs for housing.

Facilitators: municipalities could work in creating ‘pre-approved’ system of offsite 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 offsite 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 CI 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 CI, there is a need to include negative externalities caused by the development and renewal of built environment products. Moreover, offsite construction products should be better at reducing these negative externalities providing benefits for the municipalities and its constituents.

6.3 Impact of recommendation on the innovativeness of the construction industry, offsite construction and the provision of housing

The proposed recommendations might impact innovation at different levels. Some of the recommendations described above might have an impact on the CI innovativeness in general and also affect offsite construction; moreover, other recommendations will have an impact on the provision of housing and also impact offsite construction. At the same time, not all recommendations of offsite construction will impact the innovativeness of the CI 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.

These recommendations were classified based on the goals they address. Four national and two local government recommendations and roles address the innovativeness of the CI 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 offsite construction innovations. These recommendations are depicted in Figure 1.

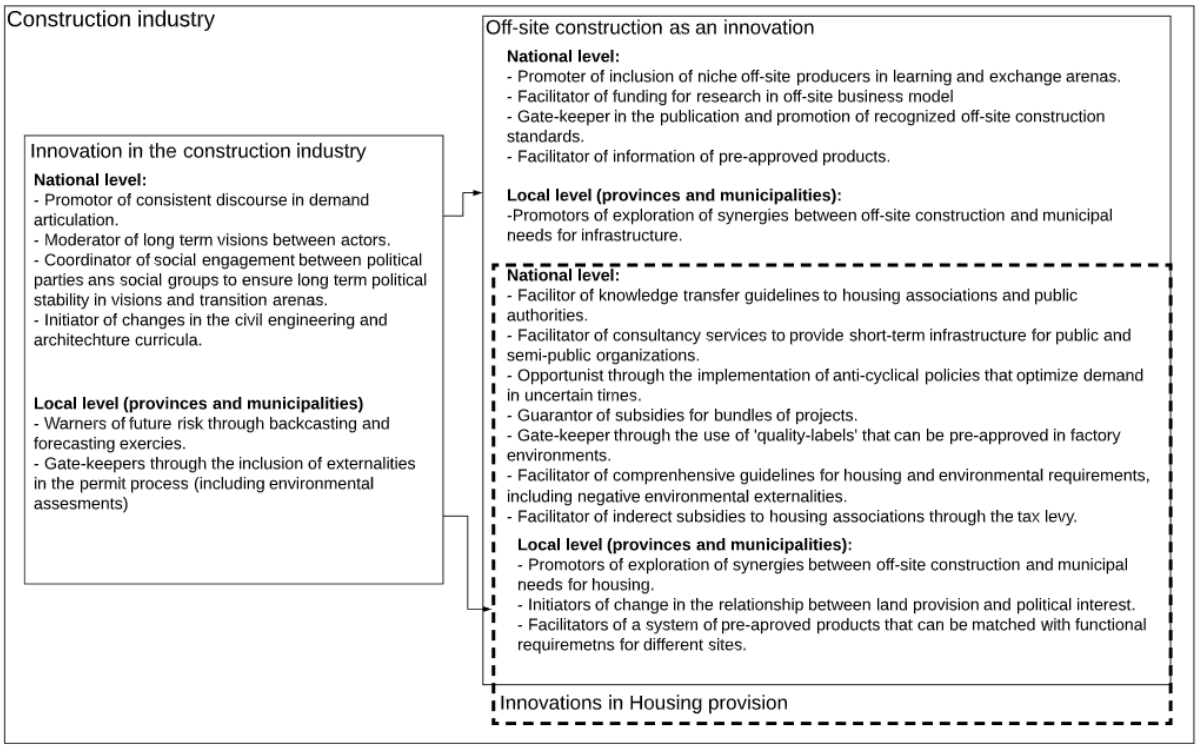

Figure 1 Goals of state roles and instruments

7 Conclusions

Public authorities might play different roles in the process of incentivizing offsite construction. We have identified 12 different roles that could help incentivize the adoption process of offsite construction products. Moreover, we have provided recommendations that should help the long-term health of the CI and improve the possibilities to fulfil its social role. Additionally, we have provided five recommendations that could be implemented at the Municipality level aimed at creating markets for offsite 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 offsite 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 CI with long term plans and be willing to compromise to achieve the potential of offsite 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 offsite construction. We highlight the capacity of Municipalities to create markets for offsite 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 CI, but they too should be willing to adapt and change.

This research aims to provide insights into the current barriers that affect the adoption and uptake of offsite construction in the Netherlands. Our recommendations were are based on the views of a selected group of actors. While offsite construction is commonly studied as an innovation, little research has been conducted on how public policy help can overcome the barrier of offsite construction. Grey literature has been produced, trying

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 CI.

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 true 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. (2008a) point out that platform approaches could benefit from the downturn of the economic cycles because, during this stage, 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 CI 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 innovative approach taken to analyse the problem of change in the CI for offsite construction adoption. The approach used in this thesis is based on the fact that offsite 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 CI, not only through offsite construction but for other technologies as well.

Through this research, we have made an exploratory effort to try to understand the reasons why a technology that promises to provide the modernization that is long due. Our societal contribution is threefold. First, we have determined what the barriers that affect different actors when opting for traditional construction methods and offsite construction methods are. Second, we proposed to evaluate offsite construction as a transformational change, comparable to the energy transition. Third, we have proposed a series of recommendations and actions that public authorities could take to improve the conditions and environment for offsite construction producers and new up-takers.

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