Incentivising Innovation in the Swedish Construction Industry

Jonas Anund Vogel

Doctoral Thesis 2020
KTH Royal Institute of Technology
School of Industrial Engineering and Management
Department of Energy Technology
Stockholm, Sweden

ISBN 978-91-7873-568-6
TRITA ITM-AVL 2020:32

Public dissertation presented at KTH Royal Institute of Technology to be examined in Lecture Hall F3, located at Lindstedtsvägen 26, Stockholm, on Friday 28 August 2020 at 10:00 in the fulfilment of requirements for the degree of Doctor of Philosophy.

Supervisors: Per Lundqvist, Hans Lind & Jaime Arias

Abstract

Almost 40 percent of global final energy use and CO_2 emissions are connected to buildings and building-related activities; it is therefore important to incentivise the design and construction of resource-efficient buildings. Unfortunately, energy demand and associated emissions in the sector continue to grow. Such incentives will help achieve energy and environmental targets, reduce costs, and make smart and sustainable buildings and cities possible at a larger scale. Because novel technologies carry risks alongside their advantages, developers, contractors and consultants must have incentives to reduce and share those risks in a rational way if we are to meet the crucial long-term societal goals of reduced use of resources and emissions.

I hypothesise that *there are legal and institutional frameworks (rules, building codes, regulations, standard contracts, etc.) that result in weak or negative incentives for construction industry actors to invest in, propose, and install resource-efficient technologies*. If the hypothesis holds true, then the goal is to identify ways to better incentivise construction industry actors to fully engage in the design and construction of smart and sustainable buildings.

To tackle this, four studies were carried out using a mixed-method approach. Paper 1 identifies 38 barriers to energy efficiency in Swedish multifamily buildings. The next study (Paper 2) develops a categorisation framework in order to understand where to engage to overcome or bypass barriers to energy efficiency. Paper 3 and 4 are devoted to analysing two sets of barriers and propose possible solutions to overcome or avoid them: (1) how the current legal framework guiding start and operation of housing co-operatives (mainly the Co-operative Act) influences incentives for engaging in resource-efficient construction, and (2) how the legal instrument for collaboration between developers and consultants incentivises resource-efficient construction. In this case, the contract under investigation is the *General Conditions of Contract for Consulting Agreements for Architectural and Engineering Assignments (ABK 09)"*. Changes to these two sets of legal and institutional frameworks could have a significant impact on how buildings are designed, produced and used. The changes proposed could incentivise construction industry actors to fully pursue the creation of smart, sustainable buildings that deliver services to

users and reduce negative environmental impacts stemming from both the building construction and operation phases.

Keywords

Energy efficiency, resource efficiency, construction industry, building sector, innovation, agreements, common-pool resources, multifamily buildings, Sweden, contract theory

Sammanfattning

Byggnader och byggande i den industrialiserade delen av världen står för nästan 40 procent av den globala energianvändningen, och därmed även en liknande procent av de globala koldioxidutsläppen. Tyvärr fortsätter energibehovet och kopplade utsläpp från sektorn att växa. Därför är det av största vikt att stimulera användningen av resurseffektiv teknik i byggnader för att minska kostnaderna, för att nå energi- och klimatmål och för att möjliggöra smarta och hållbara byggnader och städer i större skala. Eftersom ny teknik medför risker samtidigt som fördelar måste byggherrar, entreprenörer och konsulter ha incitament för att minska och dela dessa risker på ett rationellt sätt, om vi ska uppfylla de avgörande långsiktiga målen i samhället för minskad användning av resurser och minskade utsläpp.

Hypotesen i denna avhandling är att det finns lagliga och institutionella ramverk (lagar, regler, byggnormer, förordningar, standardkontrakt osv.) som resulterar i svaga eller negativa incitament för aktörer i byggindustrins att investera i, föreslå och installera resurseffektiv teknik. Om hypotesen stämmer är målet att identifiera sätt att stimulera aktörer i byggindustrins att fullt ut engagera sig i design och produktion av smarta och hållbara byggnader.

För att studera dessa frågeställningar har fyra studier genomförts, och ett brett metodupplägg har använts (mixed method approach). I artikel 1 identifieras 38 hinder för energieffektivisering i svenska flerbostadshus. Nästa studie (artikel 2) utvecklar ett kategoriseringsramerk för hinder relaterat till energieffektivitet. Artikel 3 och 4 ägnas åt två specifika hinder och föreslår möjliga lösningar för att övervinna eller runda dessa: (1) hur det nuvarande legala ramverket (främst bostadsrättsformen) som styr start och drift av bostadsrättsföreningar påverkar incitament för att uppföra resurseffektiva byggnader, och (2) hur det institutionella ramverket för samarbete mellan byggherre/entreprenör och konsulter stimulerar resurseffektiv konstruktion. I detta fall är det undersökta ramverket standardavtalet ”Allmänna bestämmelser för konsultuppdrag inom arkitekt- och ingenjörsverksamhet ABK 09”. Dessa två uppsättningar av legala och institutionella ramverk kan, om de ändras, ha en betydande inverkan på hur byggnader designas, produceras och används. De föreslagna förändringarna kan leda till möjligheter att stimulera aktörer i byggindustrin att fullt ut engagera sig i att

skapandet av smarta och hållbara byggnader; skapandet av byggnader som levererar tjänster till användare och samtidigt minskar negativ miljöpåverkan från både produktion och drift av byggnader.

Nyckelord

Energieffektivisering, resursoptimering, byggindustrin, bostadssektorn, innovation, avtal, allmänningar, flerbostadshus, kontraktsteori, Sverige

Acknowledgements

Writing this thesis would not have been possible without support from my family; considering the age of my children, this means the support of my beloved wife My. She was the one encouraging me to test something new and to find my way to academia. But most of all she has been my devoted discussion partner throughout the whole project, and she never stopped supporting me. My sons Tage and Ivar also supported me in ways they cannot yet understand: helping me to redirect my thoughts from research and details to playtime and love, providing me with renewed energy to continue towards the goal.

I have truly enjoyed the academic labour (and still do), and I feel very privileged to work at KTH and to be able to fully investigate the paths down which my different thoughts lead. But my work has not been the result of mere armchair philosophy; rather, it is a result of ongoing discussions with friends and colleagues. Most of all, I can thank my supervisor Per Lundqvist for these results. He guided me throughout the papers that comprise the project and in composing this integrated thesis. But beyond that, Per has also become a true friend and lately a travelling partner as well, as we visit places of interest for this project and for future ones. Per has also been an inspiring teacher who has shown me how to motivate both students and colleagues by successfully managing theory, practice, and humour. I also extend my deepest appreciation to Hans Lind for getting this far. His knowledge of the construction industry and its legal and institutional frameworks, and how "*en slipsten skall dras*" (kind of "knows how to play the game") in the academic environment has been of utmost importance. Discussion with Hans is always rewarding—so much knowledge concentrated in one person! I also would like to thank my supervisor, Jaime Arias, for always supporting me, for adding structure to my unstructured way of writing, and for always offering positive feedback even during difficult times.

Thanks also go out to Cyril Holm, who inspired me to read and discuss topics related to economic theory and who has been a joyful part of my academic work ever since we met, with jokes, music discussions (or maybe discussion with Per, and me listening in), and travel companionship to different Living

Labs. Thanks to Pär Blomkvist for helping me with structure and handling interesting discussions with reviewers. Thanks also to my colleagues (and boss) at Energy Technology: Björn Palm, Marco Molinari, Peter Hill and Rahmat Khodabandeh. Special thanks to Joachim Claesson, Jörgen Wallin and Nelson Sommerfeldt, who read the initial draft of this thesis; your comments were very valuable. Special thanks also to David Bohn Stoltz, Patricia Monzo, Mazyar Karampour and Behzad Monfared, who supported me in our shared office the first years. We had great fun! I would also like to thank Agnieszka Zalejska Jonsson for supporting me in everything from writing to presenting, and also for reading and commenting on my draft of this thesis Most of all, however, she has been a true friend in the academic world. Thanks to Mikael Anjou and Henrik Larsson for your wise comments and knowledge related to the Swedish construction industry. To Barbro Fröding, Maria Grunditz, Niklas Björklund, and also to all the interviewees who made my first paper possible, many thanks! Emanuel Åhlfeldt, thank you for supporting my work from start to finish, from suggesting methodological approaches to discussing details preferably over a beer or two. To Peter Kjaerboe, many thanks for all the interesting discussions during coffee breaks and walks, and for supporting me to go forward with our ideas related to the Live-In Lab.

Contents

List of Figures and Tables

List of Appended Papers

Paper 1

Anund Vogel, J., Lundqvist, P., Blomkvist, P., Arias, J., 2016, Problem areas related to energy efficiency implementation in Swedish multifamily building, *Energy Efficiency*, DOI: 10.1007/s12053-015-9352-4

Paper 2

Anund Vogel, J., Lundqvist, P., Arias, J., 2015, Categorizing barriers to energy efficiency in buildings, *Energy Procedia*, Volume 75, August 2015, pages 2839–2845

Paper 3

Anund Vogel, J., Lind, H., Lundqvist, P., 2016, Who is governing the commons: Studying Swedish housing cooperatives, *Housing, Theory and Society,* DOI: 10.1080/14036096.2016.1186730

Paper 4

Vogel, J.A., Lind, H., Holm, C. 2019. Incentivising innovation in the construction sector: the role of consulting contracts. *Construction Economics and Building*, 19:2, 181-196. https://doi.org/10.5130/AJCEB.v19i2.6613

Other publications not appended to the thesis

Anund Vogel, J., Lind, H., Lundqvist, P., 2017, Att styra allmänningar – En studie av svenska bostadsrättsföreningar, Ekonomisk Debatt, no. 2

Anund Vogel, J. Novack A, Bohn Stoltz D., 2017, KTH Live-In Lab – Testbädd för boende och byggrelaterade miljöinnovationer, Bygg & Teknik 5/17

Molinari M, Anund Vogel, J., Lazzarotto A., Acuna J., 2017, KTH Live-In Lab – Testbädd för ökad innovation i bygg- och fastighetssektorerna, Kyla & Värme, Volume 7.

Anund Vogel, J. Lind, H, Holm, C., 2019, Kontraktsutformning och incitament för innovationer och hållbarhet – exemplet ABK 09, Bygg & Teknik 3/20

Nomenclature

Abbreviations

AB 04	General Conditions of Contract for Building and Civil Engineering Works and Building Services
ABK 09	General Conditions of Contract for Consulting Agreements for Architectural and Engineering Assignments
ABT 06	General Conditions of Contract for Design and Construction Contracts for Building, Civil Engineering and Installation Works
BBR	Swedish National Board of Housing, Building and Planning Building Regulations (Boverkets Building Regulations)
DB	Design-Build contract
DBB	Design-Bid-Build contract
CPR	Common-Pool Resources
FIDIC	International Federation of Consulting Engineers
GDP	Gross Domestic Product
HVAC	Heating, Ventilation and Air Conditioning
MLP	Multilevel Perspective
OECD	Organisation for Economic Co-operation and Development
PBF	Planning and Building Ordinance
PBL	Planning and Building Act
PV	Photovoltaic
PV-T	Photovoltaic- Thermal
SCB	Statistics Sweden (Statistiska Centralbyrån)
SNM	Strategic Niche Management

1 Introduction – background and objectives

In my previous job as a project manager in the Swedish construction sector, I found myself in situations where I (in the role of developer) lacked incentives to invest in resource-saving technologies and where the consultants and contractors I hired had little interest in proposing smart and sustainable solutions. Instead, I noticed a push to use the same technologies as in previous projects, even though everyone involved knew that this would not result in any progress in terms of resource savings (electricity, heating, water, waste, materials etc). In the end, the buildings we produced were rather traditional – business as usual – and did not use any new systems, materials, technologies or services.

After five years in the construction industry, I found myself with the opportunity to investigate why there seem to be weak incentives for construction industry actors to invest in, propose and install resource-saving technologies. I transitioned from industry to academia, starting my PhD in Energy Technology at the Royal Institute of Technology in Stockholm (KTH). My goal was to investigate incentives to construct smart and sustainable buildings. The hypothesis that I formulated for this thesis is that *there are legal and institutional frameworks (rules, building codes, regulations, standard contracts, etc.) that result in weak or negative incentives for construction industry actors to invest in, propose, and install resource-efficient technologies*. If this hypothesis holds true, then a subsequent goal is to identify ways to incentivise construction industry actors to fully pursue the design and construction of smart and sustainable buildings.

Almost 40 percent of the global final energy use and CO_2 emissions are connected to buildings and building-related activities (Berardi, 2013; International Energy Agency, 2019), and thus it is important to incentivise the making of resource-efficient buildings. Energy demand from the sector continues to grow, arguably connected to three trends: 1) an increase in the welfare of developing countries, 2) greater use of energy-demanding devices, and 3) an increased quantity of housing as an effect of population growth. Also, the world population is estimated to increase from 7.7 billion to over

9.8 billion by the year 2050, which is believed will lead to a fourfold increase in global GDP and hence increased demand of natural resources (United Nations, 2019).

On a national level, Sweden's national climate target is a 50 percent increase in energy efficiency by 2030 compared to 2005 and zero greenhouse gas emissions by 2045. This calls for an urgent transformation throughout our entire society in how energy is produced, distributed and used (Swedish Government Offices, 2018). In 2016, the Swedish building and construction sector was responsible for 21 percent of greenhouse gases in Sweden (compared to the global figure of 40 percent), a share that had actually increased from 20% in 2015. This could, however, be an effect of decreased energy use in other sectors. To reach national and global environmental goals, this trend of increasing emissions needs to be reversed (Boverket, 2019). Moreover, it is important to use and develop technologies that not only help shift to carbon neutrality but also reduce resource usage in both construction and operation.

The examples above, are mostly concerned with energy efficiency and not a more overarching concept of resource efficiency, a focus reflected in the initial reasoning of the first two papers in this thesis. This does not derive from a lack of interest in other aspects but rather a lack of data related to other areas. Also, when I initiated this line of research started in 2011, my aim was to investigate incentives to invest in, propose and install energy-saving technologies. However, a lot has changed during the nine years I have pursued this question (including my personal life, which included two children, 22 months of parental leave, and four years as full-time director of KTH Live-In Lab). Energy efficiency is now only one aspect within the larger concept of sustainability (Korhonen, Honkasalo, & Seppälä, 2018). *Circularity* and the construction industry's version of *circular buildings* are terms that were not part of the initial research ideas in 2011 but that have become popular in new business models and corporate strategies (Bocken, de Pauw, Bakker, & van der Grinten, 2016). Recycling household waste – including food waste – is now standard in most Swedish households. However, the actual amount of recycling still has the potential to increase. Around 50 percent of household waste is still incinerated, mainly to produce district heating and electricity. Of the rest, 46 percent is recycled of which 15 percent is recycled as biowaste

(Avfall Sverige, 2020). In addition, during recent years water scarcity has turned into a serious problem on some parts of Sweden's eastern coast (SMHI, 2020). These changes redirected my research interests toward covering all building-related resource usage and not just energy efficiency.

The main issue this research aims to target is incentives and risks for construction industry actors to engage in resource-efficient practices. There is a need to incentivise the use of resource-efficient technologies in order to achieve energy and environmental targets, reduce costs, and make smart and sustainable buildings and cities possible at a larger scale. Because novel technology carries risks alongside its advantages, developers, contractors and consultants must have incentives to reduce and share those risks in a rational way if we are to meet the crucial long-term societal goals of reduced use of resources and emissions. This daunting task can be tackled by engaging in real-life settings in the Swedish construction industry and also digging deeper into details related to the legal and institutional frameworks that shape the incentive/risk structure for construction industry actors. In other contexts, researchers have successfully investigated the real-life situation and proposing solutions to problems possibly stemming from legal and institutional frameworks. Ellinor Ostrom (2000), for example, studied self-organisation in resource regimes and successfully identified eight design principles for the long-term survival of these resources. In another case, Ester Duflo (2017) described a strategy that delves into details in the search for solutions, employing a plumbing metaphor: the details are the 'tap work' and the 'laying of pipes.' 'The economist-plumber stands on the shoulder of scientists and engineers, but does not have the safety net of a bounded set of assumptions. She is more concerned about "how" to do things than about "what" to do. In the pursuit of good implementation of public policy, she is willing to tinker. Field experimentation is her tool of choice' (Duflo, 2017, p. 3).

But why delve into details in a large system such as the Swedish construction industry? Let me describe three situations where current legal and institutional frameworks seem to result in weak incentives for investing in and proposing resource-saving technologies.

The first example relates to a lack of incentives to invest in long-term sustainability in co-operatively owned buildings. Housing co-operatives are most often started by professional actors with short-term profit motives (developers). After construction work is completed, ownership of the co-operative's assets (one or more buildings) are then transferred to the future owners/co-operative members. The co-operative thus formed has no short-term profit motives but rather seeks long-term stability. This situation is often referred to as split incentives, where one party seeks short-term profit and the other long-term stability. This situation can lead to the initial creator of the cooperative (the developer) neglecting to invest in technologies and materials that lower long-term operating costs and extend the lifespans of systems and materials. It is rational for developers to invest just enough to sell the building, and to only install technologies that will last a bit longer than their term of liability (5–10 years). For example, in one project where I was the developer, the question of insulation and energy efficiency came up. The project involved turning an existing old warehouse into apartments. The brick walls offered limited insulation, resulting in poor energy performance. However, adding exterior insulation was not possible for building conservation reasons; thus, the alternative was to add insulation to the interior walls. Adding this insulation would have cost around 100,000 Euros and would have shrunk the floor space on each floor by 10 m^2, resulting in a total loss of 80 m^2 and a loss of value of approximately 320,000 Euros. The insulation could have lowered operating costs by about 20kWh/m^2 and would have allowed the developer change the distribution between operation costs and loan for the cooperative. This increased loan part would have lead to a gain of 250,000 Euros. Weighing the pluses and minuses, adding the insulation would have cost the developer 170,000 Euros in exchange for decreasing the future owners' operating costs over decades or maybe centuries. The walls were, therefore, not insulated.

The second example, drawn from the construction of the KTH Live-In Lab, relates to weak incentives to proposing the best available solution. Here as well, I was the developer and directed both the design and the construction of the whole test infrastructure. The aim was to produce four 22 m^2 apartments that could be transformed into eight smaller units. One consideration was the sizing of the ventilation system so that it could serve four apartments initially but also handle an increase to eight units. The interesting thing was not the solution per se but the underlying institutional framework that led to the proposed solution. Almost all developer-consultant relationships in Sweden are based on a standardised contract, the General

Conditions of Contract for Consulting Agreements for Architectural and Engineering Assignments (ABK 09). This contract stipulates that consultants are liable for the technical solutions that they propose. However, consultants can be released from liability if the developer approves. Chapter 2, section 6, states:

> The Client's approval does not release the Consultant from liability for data, the results of investigations, or technical solutions. However, the Consultant shall be released from liability where the Consultant proposes or presents technical solutions which the Consultant deems to be associated with particular risks and the Client approved the solutions. (Byggandets Kontraktskommitté, 2009)

Due to the precondition of requiring flexible infrastructure so that four apartments could be converted into eight, the ventilation system ought to be sized based on the maximum flow possible in order if the consultant is to be released from liability. Otherwise, the developer might argue that the consultant had proposed the wrong solution and demand compensation if system performance was insufficient once it was time to change to eight apartments. Thus, given how the ABK 09 frames liability, the extreme case of eight apartments resulted in the consultant proposing a solution that was a significantly oversized, expensive system for the current case of four apartments. In this situation, developers can choose to either accept the consultant's proposed solution or assume responsibility for any changes and hence release the consultant from liability.

In this case, I (the developer) told the consultant to give me the best possible solution for the case at hand, weighing costs versus scenarios where the system would potentially not deliver enough fresh air (the most extreme case being an eight-unit configuration where all eight occupants turn on the kitchen ventilation at the same time). By selecting the solution this way, I freed the consultant from liability and was able to unlock the potential of their know-how. The consultant could investigate possible solutions without risk and present the ideas to other consultants on the design team. As a result, we selected a smaller, cheaper and more efficient unit that could handle most (but not all) scenarios. This minimised costs, energy use and materials and left room in the building for other future research and development systems.

I bring up an example like this for two reasons:

- *Without technical competence*, KTH Live-In Lab would have ended up with an expensive, oversized ventilation system that would have used unnecessary material and space in a manner not aligned with sustainable production.
- *Without knowledge of the incentive structures* prescribed in the standard contract, it is hard to counteract this possible sub-optimization.

A third example is the connection between the proposal of new systems and the framework of the ABK 09 standard contract. The contract stipulates that the party proposing a solution is responsible not only for the solution but also for possible effects that the solution might have on other systems. This type of contract offers no incentives to propose new technologies, such as a wastewater heat exchanger that provides both sanitary and heating services. This system which coils incoming water pipes around drain pipes to transfer the heat from the effluent water to the incoming water. These systems do have maintenance concerns, and without proper maintenance, performance will decrease. What, then, are the incentives for consultants working with sanitation to develop and propose a sanitation system if they are then required to take responsibility for the performance of the heating system? The consultant receives no benefits but assumes significant risks. The same reasoning applies to all interconnected systems, such as combined heating and ventilation systems, solar facades and smart services that use different sensors and systems throughout the whole building.

Knowledge of legal and institutional frameworks (rules, building codes, regulations, contracts etc.) is vital in order to understand how to incentivise the use of resource-efficient technologies and materials. However, as described above, sometimes these frameworks seem to result in weak or negative incentives for construction industry actors to pursue resource efficiency. We should investigate even small details that may influence whether actors use resource-efficient construction, and if we find evidence that the framework is a barrier (as in the examples above), then we should look for opportunities for change. As mentioned earlier, Duflo (2017) describes this method as like the work of a plumber: economists stand on the shoulders of scientists and engineers in their search of *how to do things*, rather than *what to do*. Maybe a plumbing analogy works well in an economics article, but the reader may be a bit confused if the topic is buildings. Some might feel more comfortable calling this a systems approach or systems thinking, in line with the work of Peter Checkland or Donella Meadows (Checkland, 1981; Meadows, 2008). No matter the label, the point here is that details matter in understanding how the overall system performs. Without knowledge of the different parts of the system (whether it be taps, pipes, sub-systems or components), it is hard to propose solutions that optimise overall performance.

The studies were carried out using a mixed-method approach together with real-life testing of technologies and methods, primarily in the KTH Live-In Lab testbed. Paper 1 identifies problem areas related to energy efficiency in Swedish multifamily buildings. This Paper uses qualitative interviews to identify 38 barriers to energy efficiency. Paper 2 develops a categorisation framework to understand where to engage to overcome or bypass barriers to energy efficiency. Papers 3 and 4 are devoted to two sets of barriers and propose possible solutions to overcome or sidestep them. They analyse:

- How the current legal framework (mainly the Co-operative Act) guiding the construction and operation of housing co-operatives influences incentives for engaging in resource-efficient construction.
- How the legal instrument for collaboration between developers and consultants – the General Conditions of Contract for Consulting Agreements for Architectural and Engineering Assignments (ABK 09) – incentivises resource-efficient construction.

Changes to these two legal and institutional frameworks could have a significant impact on how buildings are planned, built and used. The proposed changes could incentivise construction industry actors to fully pursue creating smart, sustainable buildings that deliver services to users and reduce negative environmental impacts stemming from both construction and operation.

The examples above and the reasoning thus far illustrate the fact that the construction industry faces a social dilemma: a common-pool resource (the environment) is at the mercy of the short-term profit motives of individual actors, even though from a societal perspective it is critical that we build smart, sustainable buildings that minimise environmental impacts or even achieve positive environmental impacts, while at the same time maximising the quality of life of building users.

The remainder of this thesis is organised as follows: Section 2 describes the Swedish construction industry, Section 3 defines certain central terms, Section 4 discusses methodology and Section 5 presents the results of the studies. The thesis ends with a concluding discussion in Section 6.

2 The Swedish construction industry

2.1 The Swedish construction industry as a sociotechnical system

The Swedish construction industry, together with the production industry (construction and civil engineering trades, metal crafts and repair trades, fine mechanical, graphic and handicraft trades, installation and service trades in electricity and electronics, handicraft trades in wood, textiles etc., and food Processors), employed around 402,000 persons in 2018 (SCB, 2020) and is responsible for 10 percent of national GDP (Anjou, 2019). The industry delivers important infrastructural services and is deeply embedded in Swedish society. The construction industry employs diverse technologies, involves a wide range of actors and organisations and relies on a multitude of institutional frameworks. Buildings have relatively long lifespans compared to most other technical systems, even if certain components of buildings are changed from time to time. This long lifespan also creates a strong momentum and means that current trends are hard to change. In addition, the construction industry is rather path-dependent. However, this industry lacks central decision-making and a centrally placed system manager. Instead, decision making and risk-taking are distributed among system actors such as municipalities, developers, consultants, contractors and owners/users. It, therefore, resembles ongoing technological transitions in other primary infrastructural systems such as energy and electricity. This is not to say that the sector lacks regulation. On the contrary, the construction industry has a well-defined and well-used regulatory system that guides actors in everything from land planning to the sizing of kitchens.[1]

The Swedish construction industry can be understood in terms of what researchers describe as a socio-technical system. Socio-technical systems mix institutional and technical components with cultural and economic components. Over time they become increasingly coupled, as the components (both technical and social) evolve together towards one or more particular goals. These goals often change over time, but their direction is

[1] See section 2.4 for a summary of relevant laws and regulations.

usually pre-determined. Such systems are often centrally planned by a so-called system manager, which means that system users have limited possibilities to influence system behaviour. Sociotechnical systems often have long lifespans, exhibiting momentum, and are hence rather path-dependent and conservative. Various parties may have vested interests in the survival of such a system, enforcing their path dependency and momentum (Blomkvist & Kaijser, 1998; Hughes, 1983, 1987; Kaijser, 2002). Subsequent research has acknowledged that decision-making may also take place in a more distributed manner in systems that initially had centralised decision-making, such as with the energy infrastructure system. The new form of decision-making is instead through various forms of social networks that are expected to operate as the new governance structure and also facilitate system transition (Meza, Chappin, & Dijkema, 2008). Moreover, new technologies such as smart meters, photovoltaic technology, local electricity storage (for example, in cars), and smart home appliances can lead to new system behaviour. The formerly centrally planned system now must consider distributed decision-making from millions of smart appliances. These new connected, self-controlled systems can lead to speculation on the market, which might favour stability and load shifting but can also result in synchronization of decisions that have negative impacts on overall system performance (Nardelli & Kuhnlenz, 2018). Examples include dishwashers that start when the price for electricity is low or heating systems that shut off for a few hours during peak hours when both demand and price is high.

The Swedish construction industry is not as tightly coupled as primary infrastructural systems such as roads, railroads or telephone networks. It is more a fragmented or distributed activity that combines multiple loosely coupled activities into what we understand as the construction industry. Therefore, the Swedish construction industry can be described as a secondary distributed sociotechnical system that is strongly linked to many primary systems, such as energy, transportation, waste management and so on. Figure 1 depicts these relationships in a schematic fashion. There are, of course, many other systems that are also connected to the construction sector that are not shown in Figure 1.

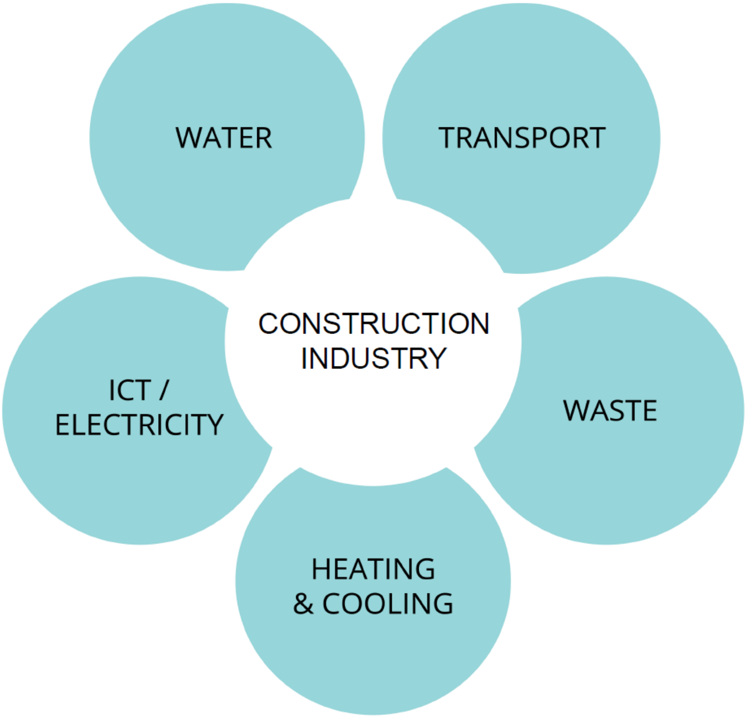

Figure 1 – Construction industry as a secondary distributed socio-technical system

2.2 The construction process, from idea to product

The process of constructing and refurbishing buildings is almost always performed as projects. A project can be defined as 'a temporary endeavour undertaken to create a unique product of service' (Project Management Institute, 2013). Projects hence have a definite beginning and end, and whatever is produced and/or developed somehow differs from earlier similar products or services. This is also typically one of the big question marks in the construction industry: why are all buildings viewed as unique? The potential for industrialisation is huge but as-of-yet untapped (McKinsey, 2016). Construction projects typically start with a pre-study phase (also called initiation phase, or ideation phase) where an actor – the developer – investigates the potential of a piece of land or a building for change or refurbishing. The Planning and Building Act defines a developer as 'a person who on his or her own behalf, carries out or allows someone else to carry out, planning, construction, demolition, or land work' (Swedish Parliament, 2010).

The pre-study phase is carried out in close coordination with municipalities, given their monopoly over planning aspects (see section 2.4). The design phase starts once there is a mutual understanding between the developer and the municipality regarding the proposed construction project. This phase is typically divided into three steps:

- *Program* – a description of the construction work, usually textual but sometimes also accompanied by sketches or drawings. The objective is to set targets for size, number of apartments/rooms, energy performance, certification level etc.
- *System drawings* – this phase translates the targets stated in the program into drawings: for example, thickness or choice of material for walls, shafts, beams are not defined in detail. The focus here is to make sure that the building components will fit within the given geometry.
- *Technical drawings* – this phase produces detailed drawings and accompanying textual documents so that the contractor can complete the agreed-on construction work. Every detail is described, from the specification of materials for all interior walls (thickness, material, soundproofing etc.) to detailed descriptions of ventilation systems, kitchens and elevators.

The construction phase (also called the execution process) most often starts before the end of the design phase. This mainly due to the economic benefits for the developer of shortening the design and construction phases in order to sell or turn over the object to the future owners sooner. The design and construction phases are accompanied by a control process, where both drawings and the production are checked against stated targets, laws and regulations (see section 2.4). Design and construction typically take from five to ten years, and operation can go on as long as the building is fit for purpose, usually around 50 to 100 years but in some cases much longer. The final stage is the closing process, where the developer turns over the building to the future owner(s). This also marks the start of the operation phase (Project Management Institute, 2013).

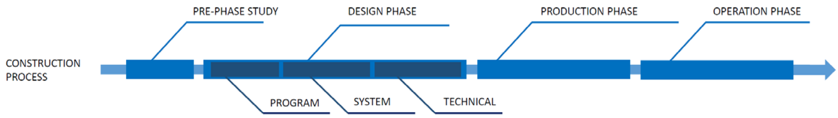

Figure 2 – The different phases of the construction process

2.3 Main actors in the Swedish construction industry

A wide range of actors is involved in the Swedish construction industry. Paper 1 started with a broad summary of actors (developers and project managers, consultants and planners, contractors, property managers, property organisation representatives, built environment conservation officers, politicians, energy conversion/distribution representatives, researchers) in order to get a picture of the *problem situation unstructured* as Peter Checkland describes it in *Systems Thinking, Systems Practice* (1981). 'It became clear that the present research was to be concerned not with problems as such but with problem situations in which there are felt to be unstructured problems, ones in which the designation of objectives is itself problematic' (ibid.).

The last two papers in this thesis focus more closely on two sets of problem situations connected to co-operatively owned buildings (Paper 3) and the standard contracts frequently used in developer-consultant relationships in Sweden (Paper 4). These papers look at four main actors:

- *Developers* who initiate projects and manage and monitor the design phase
- *Building owners* who own buildings (including co-operatives). Individual members of co-operatives are not considered building owners (see section 2.6)
- *Contractors* who perform the construction work and are also sometimes responsible for technical drawings (see section 2.5 regarding the Design-Bid-Build and Design-Build forms of construction contracts), and
- *Consultants* who design the buildings (regardless of the contracting form)

The first central actor is the developer, which the PBL defines as someone who carries out planning, construction, demolition, or land works (see section 2.2). The developer is in charge of setting targets related to the upcoming construction work and is also responsible for hiring consultants and contractors. In some cases, the developer is also responsible for establishing housing co-operatives for future homeowners (see section 2.6 for more information about housing co-operatives, as well as Paper 3 specifically). In some cases, the developer finances the actual construction work, while in other cases they are hired by a third party or actor who wants a building constructed. For this investigation, the important thing is that the developer has control over the funds.

The second central actor – the building owner – refers to individual owners of buildings, housing co-operatives, or owners of apartments in owner-occupied multifamily buildings. Because the last group is very limited in Sweden, the focus here is on the first two groups. Nevertheless, most of the arguments in this thesis are also relevant for owner-occupied multifamily buildings. The building owner may be involved in the early phases in the role of developer as well, or they may hire another actor to act as developer on their behalf. However, most of the argumentation in this thesis refers to cases where the building owner enters the scene after construction work is finished.

The third central actor in the construction process is the contractor, who is responsible for either final design and construction, or just construction of the contracted work on behalf of the developer. The contractor and the developer may be the same company, which is rather common in the construction of cooperative multifamily housing in Sweden. Contractors are divided into main (or general or prime) contractors and subcontractors in various disciplines (construction, electrical, HVAC, plumbing, building automation, etc.). A typical construction project employs around 50 different subcontractors (Larson, 2018). The form of contracting determines how these different contractors collaborate (see section 2.5). In Design-Build (DB) projects one main contractor is almost always responsible for delivering what is agreed on between the developer and contractor. The main contractor hires several subcontractors to perform parts of the contracted work. Typically around 70 percent of the scope of the contract is actually performed by subcontractors. In a Design-Bid-Build (DBB) project, there may be a general/main contractor just like in DB projects, but there are also shared contracts with may subcontractors working under a site manager hired by the developer (Larson, 2018).

The fourth set of central actors are technical consultants, who are responsible for translating the developer's ideas into a functioning product (a building, road, tunnel etc.). Consultants thus have a major impact on the design and performance of buildings. Just like contractors, technical consultants are divided into different categories depending on their field: architects, structural engineers, HVAC engineers and electrical engineers are among the most important in the construction industry. Consultants typically join the project at different stages; historically, the first to get involved in a project are the architects. They translate the developer's ideas into a functioning unit fit for the site. Once the municipality has approved the initial design, structural engineers, HVAC engineers and electrical engineers work together with the architect to develop system drawings based on the program and the initial drawings. The final technical drawings are either a product ordered by the developer (in DBB projects) or by the main contractor (in DB projects). There are around 20 different types of technical consultants involved in developing the final drawings.

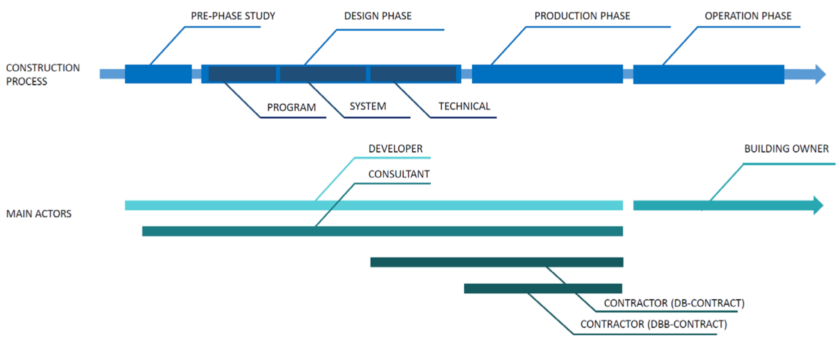

Figure 3 – Main actors and their involvement in the construction process

2.4 Laws and regulations in the Swedish construction industry

The construction process in Sweden is governed by a handful of legal documents, of which the most important are:

- Planning and Building Act (Plan och bygglagen – PBL)
- Planning and Building Ordinance (Plan och byggförordningen – PBF)
- Swedish National Board of Housing, Building and Planning Building Regulations (Boverkets byggregler – BBR)

The Planning and Building Act (PBL) contains provisions regarding the planning of land and water and construction. On a general level, the PBL aims to promote sustainable community development, equitable and satisfactory living conditions, and long-term sustainable development for existing and future generations (Swedish Parliament, 2010).

> This Act contains provisions on the planning of land and water areas, and on construction. The purpose of the provisions is, with regard to the freedom of the individual, to promote societal progress with equal and proper living conditions and a clean and sustainable habitat, for people in today's society and for future generations. (Swedish Parliament, 2010, section 1, chapter 1)

The PBL also defines the so-called *planning monopoly*, authorising municipalities to decide on plans within the framework of society. The PBL further prioritises usages that promote good management in view of the public interest.

> The purpose of planning and review in matters concerning permits or advance notices in accordance with this Act must be that, land and water areas shall be used for the purposes for which they are best suited in view of their nature and situation and of existing needs. Priority must be given to usage that promotes good management in view of the public interest. (ibid., section 2, chapter 2)

The Swedish National Board of Housing, Building and Planning Building Regulations (BBR) contains mandatory provisions and general recommendations that suggest that builder implement the PBL and the PBF. The BBR dictates performance requirements for both residential and non-residential buildings based on varying factors such as geographical location and choice of heating system (e.g., electricity/heat pumps or district heating). The BBR further outlines requirements for the thermal envelope, resource-using systems, materials, sizing of rooms and kitchens etc. According to the BBR, regulatory compliance is to be achieved through measurement of actual energy use compared with the stipulated standards (Boverket, 2011).

2.5 Contracts in the Swedish construction industry

In order to encourage the construction smart, sustainable buildings and cities, the actors involved in the construction process should be incentivised to pursue change and innovation. The terms *innovation* and *innovative technologies/methods* should here be viewed as something resulting in reduced resource usage, lower long-term costs and/or increased product quality of buildings and their various components (Borg, 2015). One major problem related to innovation is the fact that novel technology carries risks alongside its advantages; thus, tools are needed to mitigate and/or share these risks. The principal tool for collaboration and risk-sharing is the contract. The Swedish construction industry uses several standardised contracts, of which the following three are the most prominent:

- General Conditions of Contract for Consulting Agreements for Architectural and Engineering Assignments (ABK 09)
- General Conditions of Contract for Building and Civil Engineering Works and Building Services (AB 04) (for performance contracting) and;
- General Conditions of Contract for Design and Construction Contracts for Building, Civil Engineering and Facilities Works (ABT 06) (for DB contracts)

(Byggandets Kontraktskommitté, 2004, 2006, 2009)

The construction industry has a vast number of actors and many types of contracts depending on the specific tasks to be performed. The Swedish standard contract for DB projects is the ABT 06, and for DBB projects it is the AB 04. (Byggandets Kontraktskommitté, 2004, 2006). DB projects have been argued to encourage increased innovation due to the relatively larger degree of freedom (Nilsson & Nyström, 2014; Trafikverket, 2018). This fact has been said to have led the trend away from DBB and toward DB contracts (Nyström, Nilsson, & Lind, 2016). In DBB projects, the client (developer) is responsible for the design. However, case studies on road construction projects in Sweden and the UK have not yielded evidence that there is a clear relationship between contract type, degree of freedom and increased innovation (Hall, Holt, & Graves, 2000; Nyström et al., 2016). The connection between innovation and DB and DBB projects and the particular contract set-up between the developer/contractor and the technical consultants merits further investigation. The industry practice in Sweden is to use the standard General Conditions of Contract for Consulting Agreements for Architectural and Engineering Assignments (ABK 09) for both DB and DBB projects (Byggandets Kontraktskommitté, 2009).

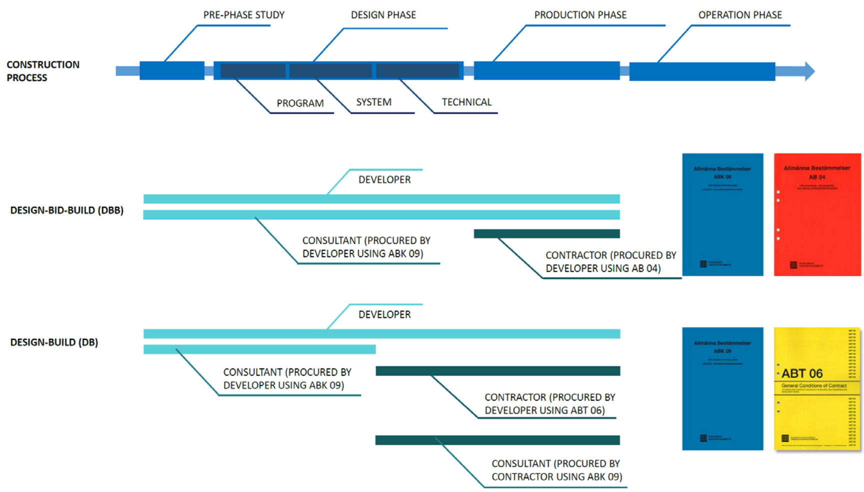

Figure 4 – Contractual connections between actors in Design-Bid-Build and Design-Build contracts.

The ABK 09 contract has been developed and updated by the non-profit Construction Contracts Committee, which also produces the AB 04 and ABT 06. This association includes contractors, consultants and building owners/developers such as the Co-operative Housing Organisation (Riksbyggen), HSB National Federation (HSB Riksförbund), Swedish Property Federation (Fastighetsägarna) and the Swedish Association of Municipal Housing Companies (SABO, Sveriges Allmännytta, tidigare Sveriges Allmännyttiga bostadsföretag) (Construction Contracts Committee, 2015). Other similar associations that develop widely used standardised construction contracts exist outside of Sweden, including the International Federation of Consulting Engineers (FIDIC) (Ndekugri, Smith, & Hughes, 2007).

2.6 Housing co-operatives in Sweden

The topic of housing was the subject of widespread debate in Sweden at the beginning of the twentieth century as a consequence of emigration caused by unsound living conditions, land division and the urbanisation trend that started in the late nineteenth century. These debates resulted in a governmental inquiry, the Housing Commission (Bostadskommissionen), which concluded that many urban lodgers and renters lived in apartments that were too small and too expensive (Swedish Parliament, 1928). In 1910 the Swedish government started to investigate co-operative forms of residential ownership, and in 1930 the Condominium Act (Bostadsrättslagen) was enacted to make it possible for citizens to purchase a residence without a large down-payment. The idea was that buildings should be owned cooperatively, governed by a board that controlled annual costs and fees (Carlsson & Rosén, 1992; Swedish Parliament, 1991).

Housing cooperatives are economic societies in a cooperative form. They are governed by and the Co-operative Society Act (Lagen om ekonomiska föreningar) and the Condominium Act (Bostadsrättslagen) (Swedish Parliament, 1987). Housing co-operatives are buildings owners in the sense that they own one or more buildings. Individual residents are, in turn, building owners only in the sense of being a member; they are also authorised to take part in the decision-making on matters relevant to the cooperative (Bengtsson, 1993). Sweden has the largest share of cooperative housing in

Europe, followed by Norway (Bengtsson & Ruonavaara, 2010). Almost 50 percent of all multifamily buildings in Sweden are owned in cooperative forms; in 2015 around 23,900 housing cooperatives were registered, owning almost 71,000,000 m^2 of heated floorspace (Fastighetsregistret i Gävle AB, 2015).

Individual co-operative members have a right to use a share of the cooperative's facilities – typically a flat/apartment – for an unlimited and unspecified period of time. Members also have the right to vote at membership meetings, to elect members to the co-operative board, and to be elected. In the sense of being a building owner, co-operatives are responsible for all actions to maintain the commonly owned assets. These typically include building operation and maintenance, capital investments, operation and maintenance of shared spaces and collective services such as waste management and cleaning of common areas. Individual members are, on the other hand, responsible for operation and maintenance connected to their specific residences. Co-operatives fund their needs through membership fees (Ruonavaara, 2005). According to the Condominium Act, all housing co-operatives must have a financial plan that describes their financial status. The plan should also consider future renovation needs. The initial idea behind co-operatives was that they should be established by the members. Nowadays, they are almost always established by developers, an external party that handles both the design and construction of the cooperative's assets (buildings) (Bengtsson, 1993). This means that the co-operative's initial board – the interim board – only consists of individuals named by the developer. This interim board is, by law, responsible for monitoring future members' interests throughout the design and construction phases. The interim board is also entrusted with developing and managing the financial plan. As soon as the majority of the apartments are sold, ownership of the co-operative, along with board responsibilities, are transferred to the future owners/members (Swedish Parliament, 1987, 1991). As a result, the majority of all housing co-operatives have two distinct phases: one phase governed by an actor with short-term profit motives and the other by an actor without such short-term profit motives.

- *Design and construction* governed by the interim board (the developer), and
- *Operation* governed by the board (members of the housing co-operative).

This intersection between the two different ownership structures is defined here as the ownership border (see Figure 5), in which design and construction are on one side and ownership and operation on the other.

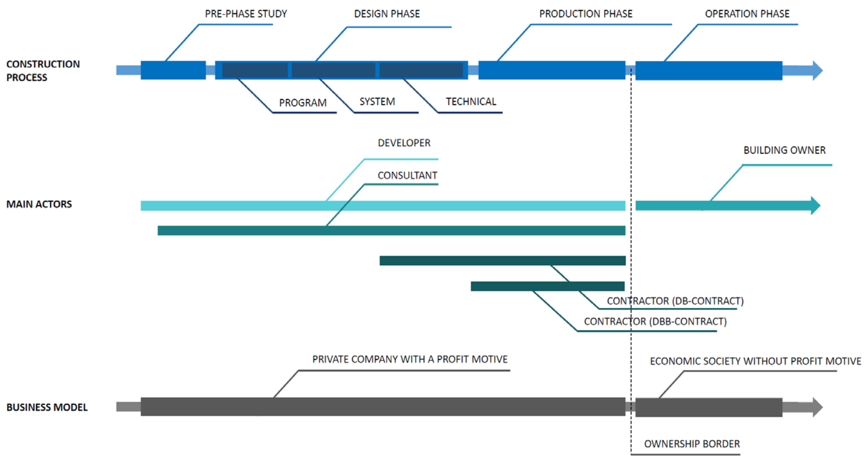

Figure 5 – Economic structure and ownership border in the co-operative housing sector in Sweden

3 Key definitions

3.1 Problem areas and barriers

The goal, as stated in the introduction, is to identify ways to incentivise construction industry actors to fully pursue in the design and construction of smart, sustainable buildings. I choose to tackle this task by first identifying possible problem areas or barriers to resource efficiency. Paper 1 describes this task in detail, which resulted in 38 problem areas that then guide the rest of the research presented here.

Problem areas or barriers can also be called challenges, reverse salients or misalignments. Much has been written on the topic of barriers to energy efficiency; Sorrell et al. (2000) define barriers as 'mechanisms that inhibit investment in technologies that are both energy efficient and (apparently) economically efficient'. In this thesis, *economically efficient technologies* refer to technologies that are highly cost-effective, commercially available, identical to less efficient technologies in production and are considered free of any hidden costs (Sorrell et al., 2000). However, here I also include problem areas that not only inhibit but also influence different actors' incentives to invest in, propose and install resource-efficient technologies. This covers a wider range of problem areas, as well as the underpinning laws and institutional frameworks and their effects on actor behaviour.

The term *barrier* exists in polarity with *driver* as its opposite. However, the problem areas discussed here seldom have an identifiable polarity; rather, they change depending on the situation and timeframe in question. Thomas P. Hughes (1992) introduced another way to view barriers or drivers. He developed the terminology of *reverse salients* –system components that lag in development, and *salients* –system components that advance ahead of other system components. This terminology describes the occurrence of change and incentives for innovations in a system. Salients and reverse salients lead to misalignments in the front of advance in a given system. This misalignment results not only from technical aspects but also from, for example, actor conflicts or conflicts in legal and institutional frameworks. In the case at hand, the sector has seen progress in both technical systems such HVAC and in energy storage and production (PVs and PV-Ts). However, systems and buildings must be connected in order to reap the full potential of innovative systems. Building Management Systems (BMS) are reverse salients in the construction sector (see Figure 6) – not because they do not exist but because they are so rarely implemented.

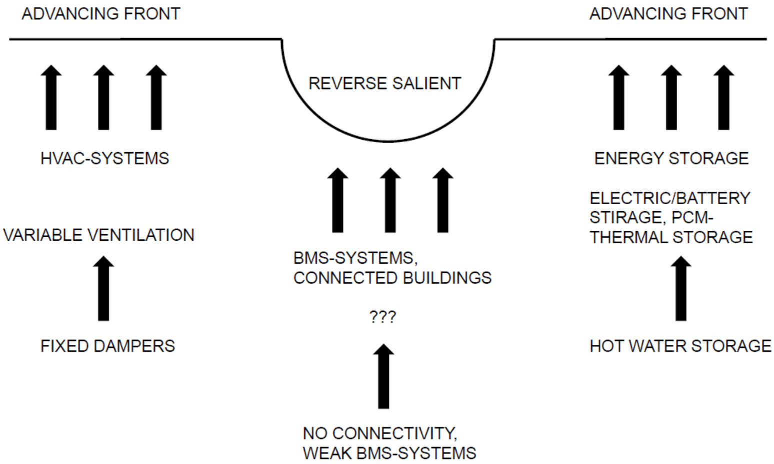

Figure 6 – Building Management Systems (BMS) as a reverse salient in the construction sector

3.2 Social Dilemmas

Laws, rules and regulations can be effective mechanisms to solve social dilemmas (Ostrom, 1990). A social dilemma is a situation in which short-term incentives for participants lead to actions with long-term negative consequences for society (Ostrom, 2005). Social dilemmas often occur in situations involving common-pool resources (Ostrom, 2005), such as rainforests, fresh water, clean air or co-operatively owned buildings (Anund Vogel, Lind, et al., 2016; Holm, 2015). Laws can mitigate situations where short-term individual incentives are detrimental to the long-term stability of shared assets (Ostrom, 1990). Broadly accepted rules and regulations can thus serve to solve social dilemmas and secure assets of importance to the long-term welfare of society.

4 Research methods and conceptual frameworks

4.1 Mixed-method approach

The construction industry is (as described in section 2.1) viewed as a secondary distributed sociotechnical system. It is a dynamic and complex system with distributed decision-making, different business models, and stakeholders with profoundly different views and knowledge of building-related innovation and technology. The methods for each paper were chosen based on the nature of the problem area under investigation. Investigating complex structures such as sociotechnical systems calls for a mixed-method approach that enables problems to be investigated from different angles. The strength of a mixed-method approach is that it can deliver results and insights into the specific area of interest in many different ways (Creswell & Clark, 2010; Hesse-Biber, 2010). One weakness of the method is that it might not delve deeply enough into specific areas and may leave too many loose ends. These aspects are discussed under each method and framework.

The individual papers do not correspond specific projects or timelines; rather, they look at current structures and practices from a rational actor's point of view, focusing on the four main actors (see section 2.3). Here *rational* means the maximization of one's own personal desires or maximization of subjective utility (Palmer, 2015). Building a good model or picture of the problem situation at hand requires an understanding of the legal and institutional frameworks related to the specific areas under investigation. Insufficient knowledge might lead to mistaken simplifications and result in invalid conclusions. The same reasoning also applies when using a more informal approach. The primary method used was an informal deductive approach focusing on what rational, profit-maximising building owners, developers, contractors and consultants would do in different institutional environments. A theoretical starting point is that projects cannot be studied as isolated units, as they are always influenced by organisational conditions (Kreiner, 1996) and prevailing institutional conditions (Collins, 1998). Here, institutional theory is central to analysing projects as complex, contradictory and embedded in an institutional context (Powell & Colyvas, 2007). The view of the institutional environment throughout the whole of the research, from Paper 1 to 4, is largely influenced by three sets of empirical findings (cases):

1. The first case is a series of semi-structured interviews fully described in Paper 1. In this study, 13 construction industry experts were interviewed regarding barriers to energy efficiency in multifamily buildings.

2. The second case is a study of an innovative construction project, Kv Forskningen 1 (305 apartments in three plus-energy buildings) in Stockholm. The second case was inspired by an interactive research approach (Nielsen & Svensson, 2006); its empirical data was gathered through participation in planning meetings and discussions and a review of project-related documents that included contracts, meeting protocols and drawings, provided primarily by the developer's project manager. One important selection criterion for the case study was that the project should include objectives targeting some form of sustainability or resource efficiency and thus the inclusion of new technologies. The chosen case sought to become a plus-energy building. In this case study, the consultants were hired using ABK 09, but the developer assumed liability for the overall energy performance of the buildings, which is not normally the case.

3. The third case looks at the roles of developer and manager of the KTH Live-In Lab testing infrastructure. This third case was also inspired by an interactive research approach (Nielsen & Svensson, 2006); its empirical data was drawn from leading and participating in planning meetings, discussions, and project-related documents. KTH Live-In Lab is a platform for accelerating innovation in the built environment and has a set of testbeds, one of which was produced during the writing of Papers 3 and 4 (KTH Live-In Lab, 2020). The empirical data from this third case are similar to the second case but also include planning and executing the design and construction of the test infrastructure (consisting of four apartments, one office and one basement for technical facilities).

My research did not examine any case of more traditional construction, mainly because it was assumed that traditional construction would include fewer innovative technologies, and hence actors would not face the same degree of risks and incentives related to those technologies as would more innovative construction projects.

Below I provide a more detailed description of the methods used and the theoretical frameworks incorporated. The individual Papers offer fuller descriptions of how the methods and frameworks were used.

Table 1 – Methods and frameworks used in the papers

	Methods			**Frameworks**			
Paper	Literature review	Qualitative interviews	Informal deductive analysis	Strategic niche management	Multilevel perspective	Common-pool resources	Contract theory
1	x	x					
2	x		x	x	x		
3	x		x			x	
4	x		x				x

4.2 Research methods

4.2.1 Literature review

The literature surveys sought to ground the research topics in various specific areas of knowledge. The literature review for Paper 1 focused on identifying problem areas related to energy efficiency implementation in multifamily buildings. It also served as a basis for developing the interview guide for the subsequent qualitative interviews (see section 4.2.2). The literature reviews for Paper 2 focused on articles related to socio-technical systems, systems thinking, multilevel perspective, and innovation journeys in order to lay the foundation for the conceptual discussion of the Swedish construction industry as a sociotechnical system. The literature review for Paper 3 focused on Swedish housing co-operatives and governance processes related to common-pool resources. Lastly, the literature review for Paper 4 focused on contract theory and contracts used in the construction sector.

The literature reviews do not claim to identify everything related to the specific studies; rather, they provide a basis for the subsequent methodological steps used in the individual articles.

4.2.2 Qualitative interviews

The literature study in Paper 1 was followed by qualitative interviews that present a deeper, more complex picture of barriers the construction industry faces. Qualitative studies are suitable for analysing processes and contextual preconditions and yield a deeper understanding of the problem areas identified in the literature reviews. The interviewees' answers to the same question sometimes differed from what was found in the literature reviews. These divergent answers were used to reveal areas that merit correction, as well as areas where such differences reveal a dynamic situation in the construction industry. The interviews were mainly conducted in order to investigate whether industry actors also perceived the problem areas identified through the literature reviews as problematic. Thirteen semi-structured interviews (Fejes & Thornberg, 2009) elicited information from actors from different areas of the Swedish construction industry. The interviews were conducted between January and March 2012. The informants were chosen partly based on their involvement in different aspects of the construction process, using a chain-referral sampling method (Heckathorn, 2002). This method is suitable when members of the targeted population know one another as members of the population, as is the case in the Swedish construction industry. Interviews were ultimately conducted with the following types of actors:

- Building owners/project managers
- Planners/consultants
- Contractors
- Property managers
- Property organisation representatives
- Building inspectors
- Politicians

- Energy conversion/distribution representatives
- Researchers

The Swedish construction industry includes a vast number of actors, and not all of them were identified or interviewed. An expanded set of interviews that included different types of actors or more examples of the same type of actor might have identified additional problem areas. In this type of research, however, the sample group should be as large as needed to sufficiently understand the situation of interest and fulfilling the purpose of the study. In this case, the purpose was not to achieve generalisability or identify all possible problem situations faced by all possible actors. Rather, the goal was to benchmark the problems identified in the current literature with a sufficiently large sample group. In the end, 13 actors were interviewed; and literature suggests sample sizes of around 15 ±10 interviewees for qualitative studies (Kvale, 1996). The results of the interviews should be viewed in light of that number. No new material was uncovered in the last interview, which indicated some form of saturation (Mason, 2010), and it was deemed that enough material had been uncovered to move on to coding and analysis.

Interviews with relatively few individuals might miss out or overestimate problems perceived by specific individuals; problems perceived by one consultant, for example, might not concern other consultants. To address this situation, answers were triangulated both between interviewees and also against the results from the literature review. Challenges mentioned solely by one interviewee without ratification from others or from the recent literature were left out of the results section. A larger number of interviewees might have increased the validity of the results. However, as argued above, an interactive approach where results from the literature review were compared with interview responses allowed for identification and correction of discrepancies. The chain-referral method for identifying interviewees was chosen based on the assumption that the Swedish construction industry is a well-defined group where actors in the population are densely interconnected. The interview process was not intended to be representative of all actors in the construction industry. Rather, it sought to investigate the connection between barriers identified in the literature and those perceived by actors in an interconnected sociotechnical system. There are at least four bias-related issues that merit discussion with this method. First, the initial sample was not drawn randomly, and hence it follows that inferences related to subsequent interviewees must be related to the initial sample. Second, such samples are often biased by voluntarism, where the most extreme case often is the initial sample. Initial participants are often known to the researchers and have networks that also could be affected by this bias. Third, participants might refer to persons with whom they have social ties. Fourth, participants are often linked through networks, and hence actors with large networks might be overrepresented (Heckathorn, 2002). These issues were all discussed prior to conducting the interviews but were deemed to be of limited significance given the purpose of the study.

In addition to the above-mentioned criticism of the chosen method, a quantitative approach would also have been a viable alternative that could possibly have led to a shift of focus.

The interviews were designed to identify two sets of information: first, how participants perceived their occupation in relation to energy efficiency, and second, their ideas related to the issues identified in the literature. The questions in the interview guide varied depending on the type of actor, but all the guides used the same introductory questions. See Paper 1, Table 2 for a selection of key questions from the interview guide. Because the interviews followed a semi-structured process, interviewees were allowed to stray away from the topics in the interview guide. In this study the interview guide was not presented to the interviewees in advance. The interviews ranged from 44 to 73 minutes long (see Table 2).

Table 2 – Interviewees / Key actors and interview length in Anund Vogel et al. (2016)

Actor / Job function	Process involvement	Number of interviewees	Interview length
Estate manager	Design, operation	2	01:30:01
Property trade organisation representative	Design, operation	1	01:10:21
Building owner/project manager	Initiating, design, execution, controlling, closing, operation	1	00:57:24
Politician	Initiating, design	1	00:44:03
Planner	Initiating, design, execution	3	03:23:34
Building inspector	Initiating, design	1	00:53:57
Researcher	Initiating, design, execution, controlling, closing, operation	2	01:30:08
Contractor	Execution, controlling, closing,	1	00:54:00
Energy conversion/distribution representative	Initiating, design, operation	1	01:11:30
Total		**13**	**12:14:58**

4.2.3 Informal deductive analysis

Papers 3 and 4 were intended primarily to identify how to overcome or sidestep problem areas related to two legal and institutional frameworks. An informal deductive approach was deemed most suitable for this goal. The approach is frequently used in other fields for other purposes, such as deductive mathematical modelling commonly used in theoretical economics. Although these mathematical models are used for different purposes, one common usage is to find out what *could* happen in a specific situation. By making assumptions regarding the situation at hand and the actors' motives, it is possible to deduce what will happen. Models always include some form of simplifications and simplifying assumptions, and hence it is not possible to conclude that the model reflects reality faithfully. Nevertheless, the fact that certain things happen in the model does indicate that these same things could happen in reality. This model describes what Sugden (2000) calls a 'credible world'. Thus, the fundamental methodological idea is the same, even though no mathematical models were built in this thesis or in the individual papers. The idea, then, is that one can investigate how rational individuals with a certain level of risk aversion would be expected to behave in a specific situation—in this case, when the relationship to the other parties is regulated by different sets of laws or institutional frameworks. Here we are interested in the problem situation per se, not the exact figure or potential in kWh or reduction in CO_2-emissions. Papers 2, 3 and 4 use a deductive approach; however, Paper 2 also includes a conceptual analysis of the Swedish construction industry.

The criticism of the "rational man" has been mainly in relation to smaller groups. Kahneman, Thaler and their various co-authors (Kahneman, Knetsch, & Thaler, 1990; Tversky & Kahneman, 1971) have shown that people do not behave in an economically rational manner when we look at specific decisions: for example, not looking at the price tag when buying food. However, this thesis looks at the construction industry as a whole and at the different actors as parts of groups (developers, consultants, contractors and building owners). It does not focus on single individuals and their specific decisions.

4.3 Conceptual frameworks

4.3.1 Strategic Niche Management and Multi-Level Perspective

Sociotechnical systems are, in general, rather stable, but they do change slowly. In order to understand the actual acceptance of new technologies from the time they are introduced and tested in single building projects to the point where they become regular parts of how buildings are produced and operated, this thesis builds on work by Schot & Geels (2008) that developed the theories of Strategic Niche Management (SNM) and Multilevel Perspective (MLP). SNM theory draws on earlier theories of technical change, arguing that actors both anticipate future selection and also actively shape the selection process itself through R&D or demonstration projects. R&D and demonstration projects are shelters where novelties are tested and developed;

they are so-called *technological niches* (Rip, 1992, 1995; Schot, 1992, 1998). These proposed niches provide protected spaces to test the design, alignment, demand, and wider sustainability issues of new technologies, encouraging interaction between issues and their connected actors.

SNM theory is useful for investigating innovations that are both socially desirable and misaligned with existing technological infrastructure, regulations, user behaviour etc. For example, a dishwasher can react to price signals for electricity, but as long as the price is the same both day and night the product cannot deliver any surplus value compared to a regular dishwasher. The same technology, however, would both save money for the owner and help reduce energy peaks if it could respond to for example price signals. Another example is greywater recycling, where the same water can be used multiple times, thus reducing the need for fresh water by 60 to 80 percent (Agudelo-Vera, Keesman, Mels, & Rijnaarts, 2013). However, user preferences and regulations related to hot water slows the process of broader acceptance.

Technological testbeds or demonstration projects are vital for exploring possible problem areas related to user behaviour and technology (Schot & Geels, 2008). Early SNM studies argued that this exploration and exposure of new technologies would lead to changes on the niche level (single projects, demonstration projects, testbed etc.), phasing out dominant, polluting technologies and replacing them with novel more sustainable ones, thus influencing and transforming the socio-technical regime: in this case, the way we use and produce buildings (see below for a longer definition).

SNM theory argues that R&D and demonstration projects are vital to providing the conditions for change. However, the actors involved in these projects might look to their benefits and short-term profit while neglecting their wider impact on a societal level. Recent work employing SNM tries to overcome these institutional barriers and incorporate measures 'which modulate emerging windows of opportunity external to the niche' (Schot & Geels, 2008). Recent work using SNM also accepts that internal niche developments are not the single factor leading to change, and it has identified that factors external to niches are crucial for achieving technological transition and regime shifts. Rip and Kemp (1998) proposed a framework for investigating niche-internal and -external processes. They combined SNM with a multilevel perspective (MLP) in which interaction between processes at different levels is the key to understanding technology transition. They propose three analytical levels to understand and investigate technology transition: the niche level, the socio-technical regime, and the sociotechnical landscape. The descriptions of the levels below are also found in Paper 2 (Anund Vogel, Lundqvist, & Arias, 2015):

- *The niche level* derives from the idea that radical novelties (innovations) are developed in niches that enable cross-disciplinary experimentation. These niches enable specified interactions between issues and actors. It is suggested that well-developed niches act as building blocks for change; they are central to regime shifts. Niches are often subsidised by governments to support not-yet-profitable innovations that are expected to yield future societal benefits (Schot & Geels, 2008).

- *The sociotechnical regime* is the ruleset embedded in 'engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artefacts and persons, ways of defining problems; all of them embedded in institutions and infrastructures' (Geels & Kemp, 2007). Sociotechnical regimes ensure stability in systems: i.e., they dictate guiding principles for products and processes.

- *The sociotechnical landscape* is, according to Schot and Geels (2007), characterised by the currently undisputed set of rules that guide technical design, shape market development and regulate these markets. The socio-technical landscape includes the institutional and market aspects required in order for the lower levels to function.

Recent work using the SNM approach still holds niche innovations as important factors for change but emphasizes the criticalness of alignment of processes at multiple levels for achieving wider impact and bringing about regime shifts. However, innovation as technological transition is typically attached to primary, tightly coupled systems. My thesis investigates the Swedish construction industry as a secondary system connected to a wide range of primary systems. Instead of being centrally governed, the construction industry has decentralised decision-making among various actors; however, it exhibits the same path dependency and momentum as many primary infrastructural systems. We can see this same type of reasoning in the study by Berkers and Geels (2011) of system innovation through stepwise reconfiguration instead of substitution. Berkers and Geels propose that in distributed systems lacking real core-technologies that function through the interplay of multiple technologies, innovation is more likely to appear in the form of stepwise reconfiguration. 'Systems are gradually transformed as multiple component innovations are adopted of multiple components' (Berkers & Geels, 2011).

Instead of only investigating innovation as coming out of technological niches, they argue that in these distributed systems innovation can be directed at components (modular innovation), architectures (architectural innovation) or a combination of both (radical innovation).

To summarise: (1) novelties are developed in technological niches and introduced into existing buildings or 'architecture'. This type of innovation can be considered stepwise reconfiguration directed at components (modular innovation); (2) existing buildings are reconfigured, either through add-ons or by replacing older components – so-called architectural innovation, and (3) components are allowed to reach their full potential, leading to radical improvements or radical innovation. Technologies (energy-efficient windows, heat recovery systems, extra insulation etc.) are introduced at the project level (in single construction/demonstration projects), and if successful, they influence the sector level, changing objectives for forthcoming construction projects. New technologies are gradually accepted and become a regular part of how buildings are planned, produced and operated, gradually transforming the concepts of how buildings should be designed. In other words, this leads to radical change and the transformation of the socio-technical landscape: transformation at the regulatory level (see Figure 8)

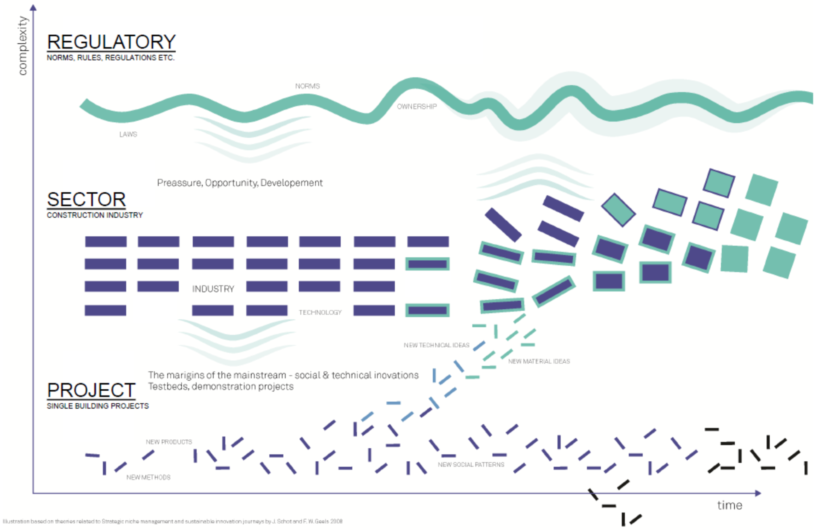

Figure 7 – Multilevel perspective on innovation, and innovation as reconfiguration pattern. Illustration based on Figure 3 in Berkers and Geels (2011), and Figure 5 in Schot and Geels (2008).

4.3.2 Common-pool resources

Common-Pool Resources (CPRs) are user-managed natural and/or artificial resources. Typical CPRs include things such as meadows, irrigation systems, road networks etc. CPRs are managed using a bottom-up approach and vary in size, most often from small- to medium-sized (Ostrom, 1990, 2000, 2005). One of the takeaways from Ostrom's work is that context matters in how actors behave in cooperative actions. The structure of cooperation within the CPR affects opportunities for achieving the common good. A large number of contextual variables influences the level of collaboration and hence the output. These variables include the common understanding of the group, group size and group heterogeneity. To identify the most prominent variables in the success of CPRs, Ostrom examined structural similarities among self-organised systems that have historically been able to survive and adapt to changes in their surroundings. This work resulted in eight design principles for the long-term survival of self-organised resource regimes that describe conditions believed to be crucial to sustaining group action when facing common dilemmas in order to prevent weakening of CPRs. Below is a brief overview of the design principles (Ostrom, 2000):

1. Presence of clear boundary rules.
2. Local rules-in-use that restrict harvesting resources and allocate benefits in proportion to the required inputs.
3. Stakeholders can participate in making and modifying CPR rules.
4. Monitors are selected who are accountable to users, to keep an eye on resource conditions and user behaviour.
5. Graduated sanctions depending on the seriousness and context of the offence.
6. Access to local conflict-solving arenas.
7. Users have minimal recognition of their rights to organise.
8. Presence of governance activities organised in multiple layers of nested enterprises.

These eight design principles are, of course, not fully applicable to all resource regimes. They must be matched to the type of community involved and the associated institutional frameworks (Ostrom, 2005).

4.3.3 Contract theory

General contract theory builds on the cornerstone of economic philosophy, namely that if we specialise in doing what we do best, we improve productivity. In Adam Smith's words, 'The greatest improvement in the productive powers of labour, and the greater part of the skill, dexterity, and judgment with which it is any where directed, or applied, seem to have been the effects of the division of labour' (1776).

However, if we specialise in making just one item, there will be several other items that we do not possess. We then engage in exchange to procure those items. The effect of specialisation and exchange is economic growth. On more recent economic theorising, law has important functions in relation to the specialisation and exchange: for example, to lower transaction costs (Coase, 1937). That is, law lowers the cost of doing business as compared to a lawless situation. While the cost of negotiating and upholding a contract is a cost of doing business, it is a lower cost than doing business without that institutional framework. This function of law, then, serves to extend social cooperation by lowering its cost (Holm, 2015).

Another example is the function of rules to solve social dilemmas: that is, law mitigates situations in which the short-term individual incentives are detrimental to the long-term stability of some asset, such as fresh water, fish, a trust, tax revenues or a stable climate (Ostrom, 1990). As section 4.3.2 above notes, common rules, regulations and laws can, if correctly designed, be effective tools to solve social dilemmas. They can mitigate situations where the short-term interests of individual actors are detrimental to the long-term survival of shared assets. Commonly used and accepted rules, regulations and laws can thus function to solve social dilemmas and secure the longevity of important assets for common use (Ostrom, 1990).

Paper 4 of this thesis uses contract theory, mainly the work of Holmström and Milgrom on how to optimise the principal/agent relation, focusing on what rational, profit-maximising actors (in this case developers and consultants) would do in different institutional environments (Coase, 1937, 1960; Holmström & Milgrom, 1991, 1994; Ostrom, 1990, 2005). There are always conflicts of interest in a principal/agent relation: for example, when a developer contracts a consultant or a contractor to plan or construct a building on the developer's behalf. The developer wants construction to happen on time and on budget, whilst delivering top quality. Meanwhile, the consultant and contractor want to complete the contracted work using the fewest possible resources in relation to the remuneration. However, a more recent trend involves contracting at a low hourly rate and then increasing the man-hours spent on the contracted work in order to increase remuneration. The principal/agent relation is also influenced by information asymmetries, negatively influencing incentives to allocate resources in ways to optimise the end-product, but rather focusing on cost/time optimisation. In most cases in the Swedish construction industry, it is the consultant or contractor who has more first-hand information about what they are constructing and hence opportunities to use this information asymmetry in their favour.

The main takeaways from mainly Holmström's and Milgrom's work is that incentive structures are pivotal in avoiding sub-optimal performance. Incentive structures may be distorted by focusing on easily measured parameters. To counteract that (and other issues), Holmström and Milgrom (Holmström, 1979; Holmström & Milgrom, 1991, 1994) developed a set of tools or ideas to fine-tune contractual incentive structures aiming at optimising performance. Performance in this case is not related to the product (buildings, components etc.), but rather the contracted parties or individuals. By critically reviewing the standard contract ABK 09, and comparing the different sections and clauses with this toolbox, three main areas are identified as deserving further investigation. This with an aim to identify ways to balance short-term self-interest with long-term societal interests in the Swedish construction industry. The three areas are following, and can also be found in Paper 4 (Anund Vogel, Lind, & Holm, 2019).

- *Risk* – A perception of shared risk leads to acting on productive incentives (Holmström & Milgrom, 1994). Agents can be risk-averse or risk-neutral, and contracts need to handle both extremes by properly managing risk versus incentives (Holm, 2018; Wahlgren, 2013). However, research strongly suggests that inexperienced agents are more likely to be risk-averse and tend to provide solutions that adhere to market consensus rather than solutions put forward by more experienced and risk-neutral agents. Inexperienced agents simply have more to lose by being wrong: their capabilities are more uncertainty, and therefore they tend to "play it safe" and seek to avoid "standing out from the crowd" (Ackerberg & Botticini, 2002; Hong, Kubik, & Solomon, 2000; Scharfstein & Stein, 1990).
- *Time* – Another pivotal problem in any principal/agent relationship is time. Many issues in such relations arise because the risk transfers from one party to the other at a certain stipulated time, eliminating incentives to achieve enduring quality and performance of a product. The issue of time is one overarching issue in the principal/agent relationship.
- *Incentives* – Contracts can be designed to incentivise performance by linking the agent's profit to observable and verifiable performance benchmarks. Performance-benchmarked contracts are often imprecise and have well-known drawbacks insofar as they are dependent on factors that may be beyond the principal's control. This results in a trade-off between offering incentives and sharing risks (Holmström & Milgrom, 1991). To overcome some of these problems, Holmström (1979) developed the *informativeness principle*, which predicts that when an agent's remuneration is linked to a performance benchmark, the contract should be indexed in such a way that exogenous factors do not impact the agent's remuneration.

Actions in industries, and also in project-based sectors such as the Swedish construction industry, must be understood and investigated as multidimensional, complex, involving multiple actors/technologies etc. and can hence only be partially observed and measures. Combining such actions with tools rewarding observable measures might lead to sub-optimisations in that actors focus too much on activities that are likely to be rewarded (Holmström & Milgrom, 1991). A model, the *multitasking model* was hence developed with the aim to balances the agent's focus among different potential substitutes, weighting incentives and risks in order to achieve optimal outcomes for all involved actors (Holmström & Milgrom, 1991). In the model, different tasks are measured and rewarded differently, depending on factors such as risk-sharing, importance, their amenability to measurement, etc. The aforementioned informativeness principle can be applied in simple cases, but in more complex situations, where a balance of activities is desirable (as in project-based construction projects), the outcomes might be favoured by ignoring some performance-related information when determining actor compensation. (Holmström & Milgrom, 1991)

4.4 Critical reflection on the choice of methods and frameworks

The Swedish construction industry is a decentralised system based on the collaboration between many different actors with a variety of goals. The institutional assumptions made in this study should hence be seen as a stylised version of the institutional framework. The assumptions are not necessarily correct for all possible collaborations between developers, building owners, contractors, and consultants. The point of reference is how actors most likely would behave in a competitive market following and using existing laws and institutional frameworks as a basis for collaboration; how actors most likely would behave following and using, for example, the Co-operative Act, PBL, BBR, AB 04, ABT 06, and ABK 09. The idea is to depict what should be considered by most actors as "business as usual" but within a project with the explicit aim to design and produce resource-efficient buildings.

As described above, an interactive approach has been a fundamental part of the studies performed. During the writing of the papers in this thesis, I have been an active part in the discussion of how to change aspects ranging from management of projects to revision of the Swedish National Board of Housing, Building and Planning Building Regulations (BBR). I have participated (and also indirect through Paper 3 initiated) in a Government Investigation related to building quality, presented my ideas for several housing co-operatives, and discussed issues related to construction industry regulations in radio, TV and daily news magazines. In these situations, and many more not mentioned here, I got close to the real-life settings in the construction industry, and also close (or even inside) the decision making processes. Getting close to construction industry actors have increased the quality through anchoring my knowledge in the actual actors' knowledge, experiences and their understanding of the processes under investigation (Danermark, Ekström, Jakobsen, & Karlsson, 2003). However, being this close to the areas and actors under investigation calls for critical distance to be able to draw conclusions and analyses beyond the everyday experiences (Svensson, Ellström, & Brulin, 2007). While performing the studies it has been important to keep a clear line between me as a participant in projects, discussions, seminars etc., and me as a researcher investigating some area of interest. The interviewees or participants in the studies have been aware of my role beforehand of meetings and discussions. Also, importantly, my background as a construction industry project manager has been addressed, setting the scene for the discussions. Throughout the whole work with the papers that this thesis is based on, it has been my goal to let all types of knowledge be valued equally, from the researchers and developers perspective to the building operators and politicians. I argue that knowledge production about the different parts of the construction industry is only possible through sharing with and between different actors.

Paper 3 and 4 does not present any new empirical data and should primarily be seen as exploratory in their nature, where the theoretical exploration can be used to define questions for future empirical studies. Moreover, the possible solutions discussed in this thesis should also be investigated more thoroughly in future studies. For example, following the development of co-operatives and quality of newly constructed buildings, and empirical studies that compare standard contracts in different countries.

5 Results

5.1 Problem areas related to the implementation of energy efficiency in Swedish multifamily buildings

Paper 1 identified 38 problem areas related to energy efficiency in Swedish multifamily buildings, 7 of which were novel in the sense that at the time of publication (2015) they had not been identified in the research literature. Table 3 below summarises the barriers, dividing them into six strategic topics. See Paper 1 for a full description of how the table was constructed.

Table 3 – Summary of problem areas related to the implementation of energy efficiency in Swedish multifamily buildings

Strategic topic	Problem area
Organisation & Knowledge	1.1 – Lack of project goals and objectives 1.2 – Feedback structures weak or absent 1.3 – Resistance to change 1.4 – Lack of knowledge of details in projects 1.5 – Time-dependent knowledge 1.6 – Actor-dependent knowledge 1.7 – Weak communication structures between companies, organisations and academia
Rules & Regulations	2.1 – Weak national energy regulations for building refurbishment 2.2 – Lack of coherence among national and municipal energy regulations 2.3 – Ambiguous rules and regulations related to energy 2.4 – Market incentives to achieve energy targets unclear 2.5 – Regulations, certifications or both? No common way forward when designing multifamily buildings 2.6 – Weak national R&D inhibits development of regulations 2.7 – Systemic view absent, leading to lost opportunities 2.8 – Certifications and geography
Construction contracts & processes	3.1 – Disjointed design process 3.2 – Broken agency – different incentives for different actors 3.3 – Lack of points of contact between energy users and energy producers 3.4 – Contract structure does not promote innovation or the use of emergent technologies 3.5 – Insufficient comprehension of system benefits
Energy systems	4.1 – Lack of knowledge of/interest in energy-related topics 4.2 – Low interest of future energy-related topics 4.3 – Shifting energy contracts 4.4 – Lack of transparency in energy pricing models 4.5 – Innovation and technological advancements not in line with the design process 4.6 – Incentives for distributed energy production are unclear or absent 4.7 – Buildings as part of the energy system
Techniques & Design	5.1 – Lack of transparency that weakens the benefits of the system 5.2 – Technology lock-ins 5.3 – Lengthy feedback cycle time 5.4 – Research & development only at corporate level constrains progress 5.5 – Incentives for using the latest technology weak or absent
Economy	6.1 – Perceived increase in operating costs and risks associated with new technology 6.2 – Insufficient and inconsistent calculation methods 6.3 – Lack of knowledge about investment horizons, risks, and lifespans 6.4 – Lack of transparency in calculations 6.5 – Innovation budgets coupled to project budgets 6.6 – Technical accounting rules not in line with product lifespans

The study indicated a strong alignment between problem areas in the literature and those that interviewees expressed: 31 out of 38 problem areas identified in the interviews had earlier been described in the literature. The 7 novel ones were:

- 2.4 – Unclear incentives for actors to achieve energy targets
- 2.6 – Weak national R&D inhibiting the development of regulations:
- 3.4 – Contract structure does not promote innovation or the use of emergent technologies.
- 5.4 – Research & development only at corporate level constrain progress
- 6.2 – Insufficient and inconsistent calculation methods.
- 6.5 – Innovation budgets coupled to project budgets.
- 6.6 – Technical accounting rules not in line with product lifespans.

Strictly national-level factors, such as rules, regulations, and contracts, were the source of 12 problem areas, of which 4 were novel. However, similar studies in other countries might find the same kinds of barriers. It is also possible that a more extensive literature review would have uncovered the 7 problem areas considered novel.

The study showed that understandings of what *building* and *energy efficiency* mean vary. The answers on the introductory questions "What does a building represent for you?" and "Do you think that the implementation of energy efficiency is important when constructing and refurbishing multifamily buildings?" revealed actors interpret the scope of buildings and energy in vastly different ways depending on their role and situations. A fuller discussion can be found in Paper 1, but below is a summary of these differing interpretations:

- Buildings are both static and constantly changing.
- Buildings are a part of a context and are important in creating urban spaces and cities.
- Buildings provide shelter and are shells for activities.
- Buildings are investments for their owners.

- Buildings are turning from static energy users to dynamic energy users, hence forming a new role-play between the involved actors and the buildings.
- Buildings represent the architectural, social and cultural values of their time; buildings represent human life, culture and growth, and buildings are the yardsticks of social progress.
- Buildings are loaded with value and are value-adding objects, but sometimes need value loading.

The different views of what buildings are and represent are understandable and sound, if looking from the specific actor's point of view. However, they also indicate the complexity of dealing with buildings. Buildings are everything from static objects to investments and activities. These varying views are all correct, indicating a need for detailed studies of every single "tap and pipe" in the construction sector.

5.2 Categorisation framework for barriers to resource efficiency

Barriers to energy efficiency (or resource efficiency) have been categorised in several different ways. For example, Sorrell et al. (2000) introduced the classification *market failures*, *organisational failures*, and *non-failures*, and Weber (1997) classifies barriers as *institutional*, *market-conditioned*, *organisational*, and *behavioural*. However, to study and overcome barriers to resource efficiency in the Swedish construction industry we need a categorisation framework that includes interaction across categorisation levels, as well as an understanding of the properties of the system under investigation. The principal idea of the categorisation framework is that in order to understand how to overcome or sidestep barriers, we must first understand the basic properties of the system under investigation. The Swedish construction industry is here viewed as a secondary distributed socio-technical system (see section 2.1). When we include strategic niche management and a multilevel perspective, the system can be divided into three analytical levels: project, sector, and regulatory. If we understand the origin of and connections between barriers, I argue that it is possible to give actors on different levels of the system the means and opportunities to actually handle, manage and develop their part of the system in the desired direction. The Swedish construction industry is (as described in section 2.1) well integrated into society, has strong momentum, and shows path dependency. The result is that innovation and development occurring outside the existing socio-technical regime might not be recognised as feasible investments (Olsson Rader, 2009; Ostrom, 2005). Thus, by examining both the current system boundaries as well as its different levels, it could be possible to expand the system of investigation (in this case the Swedish construction industry). As a result, a new development that was previously perceived as too radical or unfeasible might be accepted as feasible investments. A categorisation framework based on the ideas described above divides barriers or problem areas into three analytical levels:

- *Project level* – the project level consists of specific construction projects characterised by relatively low levels of freedom in interpreting the specific governing institutional frameworks. The project level has a relatively short time frame. A typical Swedish residential building project takes approximately six to ten years: a two- to four-year pre-planning stage interfacing with the municipality, a two- to three-year design phase, and a two- to three-year construction phase.

- *Sector level* – The sector level consists of companies, organisations, institutions etc. acting outside the context of individual projects but the possibility of changing institutional structures. Actors at the sector level can manage problems that stretch out over longer timeframes than actors in specific projects. Actions such as adding exterior insulation could be perceived as a barrier if the timeframe is short (due to regulations related to building preservation, permitting etc.) but might not encounter the same problem structures if the timeframe and/or scope are expanded or changed. Areas perceived as barriers to change and innovation at the project level can be tackled at the sector level through organisational change, industry collaboration and long-term planning. Barriers at the project level can also be viewed as drivers at the sector level. However, innovation in distributed systems such as the Swedish construction industry takes place in the form of stepwise reconfiguration, as described in section 4.3.1. Extending the timeframe might result in negative factors in addition to positive ones. For example, long timeframes may result in overstretched reconfiguration processes and slowed implementation rate, and hence a slowed feedback cycle (see problem area 1.2 in Anund Vogel et al. [2016]).

- *Regulatory level* – the regulatory level consists of the legal and institutional frameworks for the lower levels. These are rules, regulations and laws such as the Planning and Building Act, the co-operative form of ownership, and the BBR, as well as and the general conditions of contract (AB, ABT and ABK), which all strongly affect conditions at the two lower levels. Here we also find the governance cultures affecting institutional practices. In addition, we also find international regulations stemming from collaboration within super-national bodies such as the European Union. Problems that challenge the system under investigation do not only originate from inside the system. Conflicts and external pressure can stem from collision against other societal institutions, rules, organisations, or systems. Hughes (1987, 1992) discusses the restrictions of sociotechnical systems and introduces the term *environment*. The term is also used in theories regarding soft systems, where the delimitations of the systems being investigated are described as *system boundaries,* the dividing line between the system and the external environment, consisting of the factors that influence the system but cannot be changed by the system (Checkland, 1981; Churchman, 1968; Meadows, 2008).

The factors creating external pressure are not directly controlled by either local management at the project level or by managers at the sector level. As section 4.3.1 indicates, change occurs on all levels of the system, but change also occurs outside the system. Changes in other segments of society can influence system development in ways that are difficult for actors within the system to uncover. A wide range of factors, such as urbanisation and global warming, can cause external pressure and influence the system in unknown directions. However, it is not within the scope of this research to address these types of general or abstract trends, even though they strongly affect system behaviour. This study tries to remain on a tighter scale, and only investigated areas directly influencing system performance and directly influencing possibilities and incentives for project- and sector-level actors to guide the system in the desired direction.

Figure 8 in section 4.3.1 illustrates the three levels of the Swedish construction industry. The regulatory level influences and is influenced by the sector level; the sector level is influenced and influences both the project and the regulatory level; and the project level influences and is influenced by the sector level.

Earlier studies – for example, Thollander et al. (2010) – made a similar attempt, dividing barriers to energy efficiency into three system levels. However, they did not connect the analytical levels to the actual system they investigated to the same degree. Moreover, they did not investigate the connection *between* problem areas on different levels, which Paper 2 argues is vital to our understanding of system performance so that it is possible to sidestep or overcome barriers to change and innovation.

The barriers identified in Paper 1 and presented in section 5.1 are categorised using the framework described above, from the developers' point of view, and also taking the different timeframes at each level into account. As stated in Paper 2:

> Each barrier is categorised by asking the questions 'Can I do anything about it?' and 'Does it matter relative to the objectives?' (Churchman, 1968). If the answer is 'Yes' to both questions, then the barrier is categorised as belonging in the 'Project level'; if 'No' to the first question and 'Yes' to the second question, then the barrier is categorised as belonging in either the 'Sector level' or the 'Contextual level'. A third question is then asked 'Can I do anything about it if expanding the timeframe and widening the scope, including also future construction projects and other strategies?'. If the answer is 'Yes' then the barrier is categorised as belonging in the 'Sector level', otherwise the 'Contextual level'.

Barrier 1.1 – *Lacking project goals and objectives* will serve as an example. Paper 1 describes this barrier as follows: 'Lacking project objectives and goals when refurbishing multifamily buildings is according to the interviewees a barrier for implementing energy efficiency measures. Without early-adopted energy-related project objectives and goals, the possibility of reaching lower energy usage and sustainability in projects decreases'. Note that this barrier arguably also holds true for building construction and not just refurbishment. The answer to the first question 'Can I do anything about it?' is 'Yes', taking both the developer's point of view and the project timeframe into consideration. The answer to the second question, 'Does it matter relative to the objectives?' is 'Yes'. This means that the specific barrier is categorised as belonging to the project level. Using this method, the 38 barriers presented in Paper 1 are categorised in Table 4 below.

Table 4 – Categorisation of barriers to energy efficiency (Anund Vogel et al., 2015)

System structure	Barrier to energy efficiency
Regulatory level	2.1 – Weak national energy regulations for building refurbishment 2.2 – Lack of coherence among national and municipal energy regulations 2.3 – Ambiguous rules and regulations related to energy 2.4 – Market incentives to achieve energy targets unclear 2.5 – Regulations, certifications or both? No common way forward when 2.6 – Weak national R&D inhibits development of regulations 2.8 – Certifications and geography 3.1 – Disjointed design process 3.2 – Broken agencies – different incentives for different actors 3.3 – Lack of points of contact between energy users and energy producers 3.4 – Contract structure does not promote innovation or the use of emergent 4.3 – Shifting energy contracts 4.4 – Lack of transparency in energy pricing models 4.5 – Innovation and technological advancements not in line with the design 4.6 – Incentives for distributed energy production are unclear or absent 4.7 – Buildings as part of the energy system
Sector level	1.2 – Feedback structures weak or absent 1.3 – Resistance to change 1.7 – Weak communication structures between companies, organisations and 2.7 – Systemic view absent, leading to lost opportunities 3.5 – Insufficient comprehension of system benefits 5.2 – Technology lock-ins 5.3 – Lengthy feedback cycle time 5.4 – Research & development only at corporate level constrains progress 5.5 – Incentives for using the latest technology weak or absent 6.5 – Innovation budgets coupled to project budgets 6.6 – Technical accounting rules not in line with product lifespans
Project level	1.1 – Lack of project goals and objectives 1.4 – Lack of knowledge of details in projects 1.5 – Time-dependent knowledge 1.6 – Actor-dependent knowledge 4.1 – Lack of knowledge of/interest in energy-related topics 4.2 – Low interest of future energy-related topics 5.1 – Lack of transparency that weakens the benefits of the system 6.1 – Perceived increase in operating costs and risks associated with new 6.2 – Insufficient and inconsistent calculation methods 6.3 – Lack of knowledge about investment horizons, risks, and lifespans 6.4 – Lack of transparency in calculations

5.3 Incentivising innovation through changes in legal and institutional frameworks

After identifying and categorising barriers, it is time to dig a bit deeper into some of the legal and institutional frameworks possibly affecting incentives in the construction industry and propose possible solutions to overcome or sidestep them. The frameworks in question concern how housing co-operatives can be started and operated and the contractual structures for collaboration between developers and consultants, i.e. ABK 09. The hypothesis is that certain legal and institutional frameworks result in weak or negative incentives for construction industry actors to invest in, propose and install resource-efficient technologies. If this hypothesis holds true, then the goal is to identify ways to incentivise construction industry actors to more frequently pursue the design and construction of smart and sustainable buildings. The main areas of interest here are two sets of problem areas identified in Paper 1.

- Problem area 2.4 – Unclear incentives for the market to achieve energy targets, which is also strongly linked to 3.2 – Broken agency – different incentives for different actors, as well as being connected to 6.1.
- Problem area 3.4 – Contract structure does not promote innovation or the use of emergent technologies, which is also strongly linked to 3.2 – Broken agency – different incentives for different actors, as well as being connected to a large number of additional problem areas (1.3, 1.4, 1.6, 3.1, 3.5, 4.5, 5.5 and 6.1)

The next two sections describe ways to meet this goal. These sections investigate two sets of legal and institutional frameworks and discuss the effects of the current structures, and also propose possible ways to restructure the frameworks to better balance risks and incentives. That is, how to incentivise actors to pursue resource efficiency so that as a society we can achieve long-term sustainability goals.

5.3.1 Incentivising resource efficiency in co-operatively owned buildings

As previously mentioned, almost half of all multifamily buildings in Sweden are owned and operated as cooperatives (Statistics Sweden, 2014). These cooperatives are often started by actors with short-term profit motives (developers) and then transferred to actors without such short-term profit motives (co-operatives and their members). In this case, the developer creates the initial interim board for the cooperative and then transfers responsibilities to the co-operative members after the building project is finished (Swedish Parliament, 1987, 1991). The different business models lead to a situation where decisions related to building design and building performance are taken by actors who lack incentives to include parameters that result in decreased operating costs and long-term sustainability. That is, developers do not have incentives to consider parameters related to resource efficiency. Section 2.6 describes this as the ownership border, where design and construction are on one side and ownership and operation on the other (see Figure 5 for an illustration of the ownership border).

This problem was investigated using a framework developed by Ostrom (2000), described in section 4.3.2. This framework was used to consider the processes of start-up, transferring ownership, and managing housing co-operatives in order to investigate a set of problems related to the long-term survival of the resource regime. The results indicate that current structures governing Swedish housing co-operatives do not satisfy all of the eight design principles promoting long-term survival of the resource regime under review. The results also indicate that four design principles arguably can be fulfilled, three are partially fulfilled and one is not fulfilled. To ensure long-term stability and to ensure collective action when facing common dilemmas, five changes are proposed: four before the transfer of ownership (from the developer to the building owners) and one afterwards. Changes are also proposed to incentivise the actors involved so that they are encouraged to construct resource-efficient buildings. The changes proposed below could be implemented separately or in combination. They are in no way radical, as we can see from empirical evidence that many smaller stepwise changes in systems with strong path dependency can lead to success where larger, more radical changes often lead to litter or no impact (Duflo, 2017; Ruonavaara, 2005). These different adjustments can be combined in a variety of ways. The changes proposed below are also discussed in Paper 3.

- *Give future residents more power during the design and construction stage.* This change means that future residents should form the majority of the board from the beginning, in a manner similar to the German *Baugemeinschaften* (in Swedish, *Byggemenskaper*), for example (Tummers, 2015). This would allow non-traditional actors to participate in the design and construction phases. This change would probably not be a possible way forward for the majority of the Swedish households, given the rather limited timeframe of households compared to normal duration of design and construction phases. However, the preconditions for these initiatives should be investigated in order to promote an increase in *Baugemeinschaften*-type projects.

- *Limit the types of companies that can be involved in the early stages of construction projects.* This could be achieved through some kind of licensing system in which only companies with a license would be allowed to launch co-operative housing projects. Licenses could initially be distributed to all companies or only to those with a track record of fairness in both design and construction, as well as in their management of the interim housing co-operative board (Paddison, Docherty, & Goodlad, 2008). Companies could lose their license if they use the asymmetric power situation unfairly: in other words if they produce low-quality buildings that they then sell as a premium goods. To re-enter the market would then require some kind of compensation to the affected co-operative.

- *Official representative on the board.* An outside representative on the board could be part of the design and construction phases; this member would certify that the building is of fair quality and presents a low risk of unexpected future costs. The idea would be that such a representative would act on behalf of the future residents who will be responsible for operating and maintaining the building and would serve as a bridge over the ownership border.

- *Increase information about the technical choices made that are presented to future unit buyers.* Detailed information related to systems and products and their quality would make it easier for future residents to evaluate the risk associated with buying a unit. The information could possibly affect the price, reducing incentives to choose low-quality systems and products (Borg, 2015).

- *Tighten up the monitoring and sanctioning process of board members who fail to make investments that would favour the majority of the co-operative members*. Such failures could be failures to chose resource-saving technologies but could also include essential renovation measures. The proposed measure would assign technical liability to the board, who would be responsible for investigating the building's technical systems and associated operating costs at least every five years and presenting at every fifth annual membership meeting. The change would ensure the optimal operation of co-operative buildings and ensure the stability of the resource regime under investigation. To counteract the already-problematic situation of finding board members, this technical review should be assigned to an outside party in order to avoid creating an additional workload for board members.

5.3.2 Incentivising innovation by changing consulting contracts

It is especially crucial to incentivise change and innovation in order to achieve energy and environmental targets and to make smart and sustainable buildings and cities possible. Because novel technology carries risks alongside its advantages, developers, contractors and consultants must have incentives to fully accept those risks if society is to meet the crucial long-term goals of reduced resource usage and emissions. These studies identified contract structures as one aspect that merits further investigation in order to understand how to incentivise actors to pursue in resource efficiency.

Here the standard contract frequently used in developer-consultant relationships is under investigation, the General Conditions of Contract for Consulting Agreements for Architectural and Engineering Assignments (ABK 09). Contracts are crucial elements in framing incentive structures for actors and in achieving real-world outcomes from those incentive structures (Coase, 1937, 1960; Holmström & Milgrom, 1991, 1994; North, 1990; North & Thomas, 1973; Ostrom, 1990, 2005). The issue of interest here concerns two problem areas identified in Paper 1: problem area 3.4 – *Agreement structure does not promote innovation or the use of emergent technologies*, which is also strongly linked to problem area 3.2 – *Broken agency – different incentives for different actors.*

In line with the hypothesis and goal of this thesis, I discuss details of the contract is under investigation and the effects related to the various clauses of ABK 09, as well as possible ways to restructure the contract to better balance risks and incentives: i.e. to incentivise actors to fully pursue resource efficiency in order to achieve long-term sustainability goals.

> Section 4.3.3 identified three main areas of contract theory that merit further investigation in relation to the standard contract ABK 09. The purpose of this is to identify ways to balance short-term self-interest against long-term societal interests in the Swedish construction industry. The three areas are risk, timeframes, and incentives. ABK 09 is compared with the three areas by looking at each section and asking the following questions (Anund Vogel et al., 2019):
>
> - Does the section in any way lead to uncompensated risks for the consultant?
> - Does the section in any way lead to uncompensated time delays for the consultant?
> - Does the section in any way incentivise consultants to propose novel or innovative technologies that can be expected to perform better in terms of resource use and contribute more to sustainability than commonly used technologies?

By looking at current industry practices for collaboration (ABK 09) in comparison with the identified aspects of contract theory, six sections in ABK 09 were identified that could lead to weak or negative incentives for consultants to propose resource-efficient technologies: sections 1 and 6 in chapter 2, sections 2 and 6 in chapter 4, and sections 1 and 2 in chapter 5. The preamble is also identified as potentially leading to weak incentives to consider aspects that are not strictly financial.

To mitigate risks and negative incentives and to incentivise consultants and developers to fully pursue resource efficiency, we propose a set of changes to ABK 09. These changes could be implemented separately or in combination in a future revision of the ABK. The proposed changes summarised below are analysed in more detail in Paper 4.

- *Differentiate liability periods* between systems that are necessary for operation (framing, vapour barriers, roofing, etc.) and systems that are optional and undergo continual changes and upgrades (ICT systems).

- *Incentivise consultants and contractors through the sharing of future profits*, allocating not only responsibilities and rewards during design and construction but also operational benefits and responsibilities. This is often referred to as a performance contract. The multitasking model (Holmström & Milgrom, 1994) indicates that agents (consultants) will redirect their efforts away from uncompensated activities and toward compensated activities. There are a number of problems with long-term incentive contracts, but this would, at a minimum, make it possible to have a five-year bonus system for consultants who achieve benchmarks for certain specific costs.

- *Formalise the procedure for identifying specific technologies and systems as professionally prudent to use.* Standardise the methods for testing and evaluation, possibly also including suppliers. This change would preferably be implemented at the national level in order to comply with national building regulations and other framework regulations, such as the municipal planning monopoly. Also, there is no exact definition of the term *professional* or guidelines for how it should be interpreted in different situations. It might seem obvious that a consultant should act in a professional manner, but the term might lead to sub-optimisation in the sense that it might create increased risks for actors proposing novel resource-saving technologies. If the introduction of such technology can be connected to increased costs or time delays, the developer might state that it was 'unprofessional' to propose it. Also, if unexpected problems arise due to the technology, the same reasoning might apply. In addition, if the proposed technology leads to increased profit for the developer, then the consultant will not be rewarded in any way.

- *Incentivise knowledge transfer.* The study indicates that it would also be desirable to see some kind of process that mitigates risk aversion among less-experienced consultants so that there are incentives for exchange on these matters between clients and consultant and so that the process of exchange within the contract inherently incentivises new technology and correctly apportions the associated risks. New technologies might also be evaluated by academic committees or government authorities, as Borg (2015) discusses.

- *Include building performance or building operation in the overall objective.* The contract could be changed to include not only the goal of optimal allocation of financial risks but also long-term building performance and sustainability.

- *Damages should be limited to extreme cases of bad faith in the contractual relationship; in other cases, they should be replaced by a model of risk-sharing.* Risk-sharing should be tied to relevant criteria so that the parties to the contract are incentivised to spend time on work that actually contributes to their partnership and risk-sharing: for example, a model that builds on Holmström's multitasking model (Holmström & Milgrom, 1991). The model of damages is one of bad faith and not necessarily one of shared risk.

5.4 My contribution to the included studies

I developed the ideas, carried out the empirical studies, collected the data, wrote the texts, and analysing the results for the four studies that this thesis includes; therefore, I am the main author of all of them. The co-authors are my supervisors in all cases except one. As supervisors, the co-authors have been of great help in discussing theories, methods, and details and in turning the rough and often overly long manuscripts into publishable journal articles. The one co-author who was not my supervisor was also of great help in identifying literature that was vital in framing that article within the legal field; because of that and their valuable discussions, they were also included as a co-author.

6 Concluding discussion

This research and its examples and individuals studies indicate that the construction industry faces what we can refer to as a social dilemma. The specific dilemma here is the common-pool resource (the environment) that is at the mercy of the short-term profit motives of individual actors. However, from a societal perspective it is of utmost importance to construct smart and sustainable buildings that minimise environmental impacts or even have a positive impact on the environment, and at the same time maximise the quality of life for building users. The hypothesis stated in the introduction is that there are legal and institutional frameworks (rules, building codes, regulations, standard contracts, etc.) resulting in weak or negative incentives for construction industry actors to invest in, propose and install resource-efficient technologies. Also, if the hypothesis holds true, then the goal is to identify ways to incentivise construction industry actors to fully pursue the design and construction of smart, sustainable buildings.

The main takeaway from my research is this: seen against the theoretical background of this thesis, the results from the individual papers support the idea that the frameworks that were studied result in weak or negative incentives for actors to pursue resource efficiency. The hypothesis seems to hold true. The studies use a mixed-method approach, and based on their findings a set of changes are proposed to the co-operative form of ownership, and the General Conditions of Contract for Consulting Agreements for Architectural and Engineering Assignments – ABK 09. The direct results of the four studies that this thesis is based on have partly been presented in section 5 but are presented in greater detail in the appended papers, in line with the goal of the research.

During these years in which I combine my research efforts with project management, it became obvious to me that different actors have vastly different incentives for investing in, proposing and installing resource efficient technologies. Balancing risks and incentives and creating long-term relationships among actors is crucial if we are to achieve our energy and environmental goals. This thesis argues that in order to do so, we need to understand how the construction industry actually functions, how and why actors interact, how different technologies can be combined and how business models influence decisions. As mentioned in the introduction, *every* *little detail that can influence actors to engage in resource-efficient construction deserves investigation, and if there are signs of malfunctioning components in the system, then there are opportunities for change*. In this work, and as detailed in the individual papers, these malfunctioning parts are described together with proposed changes that would better incentivise actors to use their knowledge and potential.

One general result is that by looking into details and specific rules and regulations, as well as how they influence actor incentives, it is possible to understand problem situations and propose ways to overcome or sidestep them. Because of the distributed nature of decision-making in the construction industry, it is crucial to investigate and understand the effects of proposed changes and/or solutions on all affected actors. Changes should not be proposed unless the underlying structures are described and understood at all levels and for all actors. This is aided by using a categorisation framework that takes the system's structure into account. The proposed way of categorising barriers opens up new ways to investigate system performance and hopefully new ways for actors to fully pursue innovation and sustainability.

When we view the Swedish construction industry as a sociotechnical system and further dividing the system into three levels, we find that many barriers related to energy efficiency and innovation stem from preconditions that project-level actors cannot influence. Of the 38 barriers identified in Paper 1. 16 originate at the regulatory level, 11 at the sector level, and 11 at the project level. Over two-thirds of the problem areas that construction industry actors view as barriers originate at levels that actors involved in individual construction projects cannot influence. By identifying the origin of barriers, we can also start the work – the 'plumbing activities' – of actually overcoming them. For example, efforts related to change and innovation most often occur on the project level. However, most barriers are located on the other two levels, so a shift in focus (to instead focusing on the sector and regulatory levels) could lead to higher probabilities of overcoming the barriers. Efforts must be aligned with underlying structures. For example, installation of new integrated technologies and building automation systems requires new building operation skills. Without proper knowledge at the sector level, individual projects risk finding themselves sub-optimised, leading to the mistaken conclusion that the new, innovative systems perform worse than old ones. The problem, in this case, lies not with the technology but rather with the organisation. The whole industry must be ready to integrate new systems and technologies: not just planners and contractors but also building operators and users. Bottom-up approaches in individual projects that are not tightly coupling with organisations at the sector level risk failing and therefore not fostering change and innovation. The construction industry has worked hard to overcome many technological barriers, however, it has failed to transfer sufficient knowledge and competence to maintenance and operations organisations and building owners. In other words, many of the barriers are organisational and structural and must be handled accordingly.

Studies of transformation processes often emphasise the importance of demonstration projects as a means to induce movement toward change. The paths forward proposed this study proposes could be tested in specific areas, over specific time periods, or combinations of both. These demonstration projects could sow the seeds of further movement towards change in current structures, leading to buildings that are better in terms of quality, purpose and resource efficiency, but also better in terms of their interior conditions for building users. Recent years have witnessed an increase in investments in pilot projects and arenas for innovation in buildings and sustainable construction. However, this thesis found that most barriers originate at the landscape level, which implies that energy and sustainability are not yet key aspects when forming and transforming the contextual preconditions that dictate how to design, produce and operate buildings in Sweden. The outcomes of pilot projects apparently require evaluation before they will have any substantial impact on design principles and regulations in the Swedish construction industry.

By leaving existing legal and institutional frameworks unchanged, we risk ending up in a situation where society desires innovation and sustainability but does not incentivise these goals. The current ways in which collaboration between construction industry actors are managed, how incentives and risks are shared and the asymmetric knowledge distribution could lead to stagnation in terms of change and innovation. If clients and developers do not assume responsibility for demanding novel and innovative technologies (which is not a reasonable expectation if they have less information concerning such technologies), consultants need to be incentivised to propose the use of such technologies, making smart and sustainable buildings the norm instead of something for the dedicated few.

Even though this thesis focuses on Sweden, similar barriers and incentive structures are found in many other countries and contexts, as Bengt Holmström, Ellinor Ostrom and Ester Duflo have discussed and investigated. As such, this thesis – which is mainly exploratory – has direct relevance for contexts other than Sweden, as well as implications for incentive structures anywhere. It is hoped that the work undertaken encourages others to investigate details – the 'taps and pipes' – in other contexts, in order to hasten the transition to smart, sustainable buildings and cities that use climate-neutral construction and achieve climate-neutral operation. The results of this thesis indicate a need for other researchers to initiate similar attempts at overcoming barriers to change and innovation in the construction industry as a means to achieve society's climate goals.

7 References

Ackerberg, D. A., & Botticini, M. (2002). Endogenous Matching and the Empirical Determinants of Contract Form Endogenous Matching and the Empirical Determinants of Contract Form Maristella Botticini. *Journal of Political Economy*, *110*(3), 564–591.

Agudelo-Vera, C. M., Keesman, K. J., Mels, A. R., & Rijnaarts, H. H. M. (2013). Evaluating the potential of improving residential water balance at building scale. *Water Research*, *47*(20), 7287–7299. https://doi.org/10.1016/j.watres.2013.10.040

Anjou, M. (2019). *The ineffective building sector*. Ekerlids.

Anund Vogel, J., Lind, H., & Holm, C. (2019). Incentivising innovation in the construction sector: The role of consulting contracts. *Construction Economics and Building*, *19*(2), 181–196. https://doi.org/10.5130/AJCEB.v19i2.6613

Anund Vogel, J., Lind, H., & Lundqvist, P. (2016). Who is Governing the Commons: Studying Swedish Housing Cooperatives. *Housing, Theory and Society*, *6096*(May), 1–21. https://doi.org/10.1080/14036096.2016.1186730

Anund Vogel, J., Lundqvist, P., & Arias, J. (2015). Categorizing barriers to energy efficiency in buildings. *Energy Procedia*, *00*, 1–8.

Anund Vogel, J., Lundqvist, P., Blomkvist, P., & Arias, J. (2016). Problem areas related to energy efficiency implementation in Swedish multifamily buildings. *Energy Efficiency*, *9*(1), 109–127. https://doi.org/r

Avfall Sverige. (2020). Avfall Sverige. Retrieved February 1, 2020, from https://www.avfallsverige.se/kunskapsbanken/avfallsstatistik/hushallsavfall/

Bengtsson, B. (1993). *Prosperous ambivalence : housing cooperatives in Sweden*. Gävle: National Swedish Institute for Building Research.

Bengtsson, B., & Ruonavaara, H. (2010). Introduction to the Special Issue: Path Dependence in Housing. *Housing, Theory & Society*, *27*(3), 193–203.

https://doi.org/10.1080/14036090903326411

Berardi, U. (2013). Clarifying the new interpretations of the concept of sustainable building. *Sustainable Cities and Society*, *8*(2013), 72–78. https://doi.org/10.1016/j.scs.2013.01.008

Berkers, E., & Geels, F. W. (2011). System innovation through stepwise reconfiguration: the case of technological transitions in Dutch greenhouse horticulture (1930–1980). *Technology Analysis & Strategic Management*, *23*(3), 227–247. https://doi.org/10.1080/09537325.2011.550392

Blomkvist, P., & Kaijser, A. (1998). *Den konstruerade världen : tekniska system i historiskt perspektiv*. Stockholm: B. Östlings Bokförlag.

Bocken, N. M. P., de Pauw, I., Bakker, C., & van der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering*, *33*(5), 308–320. https://doi.org/10.1080/21681015.2016.1172124

Borg, L. (2015). *Procurement Contracts, Innovation and Productivity in the Construction Sector: Five Studies*. Stockholm: KTH Royal Institute of Technology.

Boverket. *Boverkets building regulations.* , (2011).

Boverket. (2019). Utsläpp av växthusgaser från bygg- och fastighetssektorn. Retrieved May 5, 2019, from https://www.boverket.se/sv/byggande/hallbart-byggande-och-forvaltning/miljoindikatorer---aktuell-status/vaxthusgaser/

Byggandets Kontraktskommitté. (2004). *AB 04 - Allmänna bestämmelser för byggnads-, anläggnings- och installationsentreprenader*. AB Svensk Byggtjänst.

Byggandets Kontraktskommitté. (2006). *Allmänna bestämmelser för totalentreprenader avseende byggnads-, anläggnings- och installationsarbeten*. AB Svensk Byggtjänst.

Byggandets Kontraktskommitté. (2009). *Allmänna bestämmelser för konsultuppdrag inom arkitekt- och ingenjörsverksamhet*. AB Svensk Byggtjänst.

Carlsson, S., & Rosén, J. (1992). *Den Svenska Historien volym 14*. Stockholm:

Albert Bonniers förlag.

Checkland, P. (1981). *Systems thinking, systems practice*. John Wiley & Sons.

Churchman, C. W. (1968). *The Systems Approach*. New York: Dell Publishing Co.

Coase, R. H. (1937). The Nature of the Firm. *Economica*, *4*(16), 386–405.

Coase, R. H. (1960). The Problem of Social Cost. *The Journal of Law & Economics*, *56*(4), 837–877.

Collins, D. (1998). *Organizational Change. Sociological Perspectives*. London: Routledge.

Construction Contracts Committee. (2015). Construction Contracts Committee. Retrieved January 7, 2015, from http://www.foreningenbkk.org/index.php/the-construction-contracts-committe/

Creswell, J. W., & Clark, V. L. (2010). *Designing and conducting mixed methods research* (Thousand Oaks, Ed.). SAGE Publications Inc.

Danermark, B., Ekström, M., Jakobsen, L., & Karlsson, J. C. (2003). *Att förklara samhället* (Second Edi). Lund: Studentlitteratur.

Duflo, E. (2017). The economist as plumber. *American Economic Review*, *107*(5), 1–26. https://doi.org/10.1257/aer.p20171153

Fastighetsregistret i Gävle AB. (2015). BRF Registret. Retrieved May 21, 2015, from http://www.brfregistret.se/viewcategory.aspx?id=5&name=Eget+urval

Fejes, A., & Thornberg, R. (2009). *Handbok i kvalitativ analys*. Liber.

Geels, F. W., & Kemp, R. (2007). Dynamics in socio-technical systems: Typology of change processes and contrasting case studies. *Technology in Society*, *29*(4), 441–455.

Hall, M., Holt, R., & Graves, A. (2000). Private finance, public roads:

Configuring the supply chain in PFI highway construction. *European Journal of Purchasing and Supply Management*, *6*(3–4), 227–235. https://doi.org/10.1016/S0969-7012(00)00018-6

Heckathorn, D. D. (2002). Respondent-Driven Sampling II: Deriving Valid Population Estimates from Chain-Referral Samples of Hidden Populations. *Social Problems*, *49*(1), 11–34. https://doi.org/10.1525/sp.2002.49.1.11

Hesse-Biber, S. (2010). Qualitative approaches to mixed methods practice. *Qualitative Inquiry*, *16*(6), 455–468. https://doi.org/10.1177/1077800410364611

Holm, C. (2015). *Hayek ' s Critique of Legislation*. Uppsala University.

Holm, C. (2018). Bearing and Sharing Risk in the Swedish Welfare State. In M. Dyson (Ed.), *Regulating Risk through Private Law*. Cambridge: Intersentia.

Holmström, B. (1979). Moral Hazard and Observability. *The Bell Journal of Economics*, *10*(1), 74–91.

Holmström, B., & Milgrom, P. (1991). Multitask Principal-Agent Analyses: Incentive Contracts, Asset Ownership, and Job Design. *Journal of Law, Economics, & Organization*, *7*, 24–52. Retrieved from http://www.emeraldinsight.com/doi/10.1108/ilds.2002.12230dab.004

Holmström, B., & Milgrom, P. (1994). The Firm as an Incentive System. *The American Economic Review*, *84*(4), 972–991. Retrieved from http://www.jstor.org/stable/2646959

Hong, H., Kubik, J. D., & Solomon, A. (2000). Security Analysts ' Career Concerns and Herding of Earnings Forecasts. *The RAND Journal of Economics*, *31*(1), 121–144. Retrieved from http://www.jstor.org/stable/2601032

Hughes, T. P. (1983). *Networks of power : electrification in Western society, 1880-1930*. Baltimore: Johns Hopkins U.P.

Hughes, T. P. (1987). *The social construction of technological systems : new directions in the sociology and history of technology*. Cambridge: MIT Press.

Hughes, T. P. (1992). The Dynamics of Technological Change: Salients, Critical Problems, and Industrial Revolutions. In *Technology and Enterprise in a Historical Perspective* (pp. 97–118). Oxford: Clarendon Press.

International Energy Agency. (2019). International Energy Agency. Retrieved January 8, 2019, from https://www.iea.org/topics/energyefficiency/buildings/

Kahneman, D., Knetsch, J. L., & Thaler, R. H. (1990). Experimental Tests of the Endowment Effect and the Coase Theorem. *Journal of Political Economy*, *98*(6), 1325–1348.

Kaijser, A. (2002). System Building from Below: Institutional Change in Dutch Water Control Systems. *Technology and Culture*, *43*(3), 521–548. https://doi.org/10.1353/tech.2002.0120

Korhonen, J., Honkasalo, A., & Seppälä, J. (2018). Circular Economy: The Concept and its Limitations. *Ecological Economics*, *143*, 37–46. https://doi.org/10.1016/j.ecolecon.2017.06.041

Kreiner, K. (1996). In search of relevance: Project management in drifting environments. *Science*, *11*(4), 335–346.

KTH Live-In Lab. (2020). KTH Live-In Lab. Retrieved from www.liveinlab.kth.se

Kvale, S. (1996). *InterViews: An Introduction to Qualitative Research Interviewing.* SAGE Publications, Inc.

Larson, H. (2018). *Projektledning vid fastighetsutveckling.* AB Svensk Byggtjänst.

Mason, M. (2010). Sample Size and Saturation in PhD Studies Using Qualitative Interviews. *Forum: Qualitative Social Research*, (3).

McKinsey. (2016). *Imagine constructions digital future.*

Meadows, D. H. (2008). *Thinking in Systems.* Chelsea Gren Publishing Company.

Meza, C. M. C., Chappin, E. J. L., & Dijkema, G. P. J. (2008). Transition of energy infrastructure systems: Towards a framework for assessing the system transition process. *International Conference on Infrastructure Systems and Services: Building Networks for a Brighter Future, INFRA 2008*, (c). https://doi.org/10.1109/INFRA.2008.5439674

Nardelli, P. H. J., & Kuhnlenz, F. (2018). Why Smart Appliances May Result in a Stupid Grid: Examining the Layers of the Sociotechnical Systems. *IEEE Systems, Man, and Cybernetics Magazine*, *4*(4), 21–27. https://doi.org/10.1109/msmc.2018.2811709

Ndekugri, I., Smith, N., & Hughes, W. (2007). The engineer under FIDIC's conditions of contract for construction. *Construction Management and Economics*, *25*(7), 791–799. https://doi.org/10.1080/01446190701411216

Nielsen, K. A., & Svensson, L. G. (2006). *Action Research and Interactive Research: Beyond Practice and Theory*. Maastricht: Shaker Publishing.

Nilsson, J., & Nyström, J. (2014). *Mapping railways maintenance contracts – the case of Netherlands, Finland and UK*. Retrieved from http://vti.diva-portal.org/smash/get/diva2:771921/FULLTEXT01.pdf

North, D. C. (1990). *Institutions, Institutional Change and Economic Performance*. Cambridge: Cambridge University Press.

North, D. C., & Thomas, R. P. (1973). *The Rise of the Western World: A New Economic History*. Cambridge: Cambridge University Press.

Nyström, J., Nilsson, J. E., & Lind, H. (2016). Degrees of freedom and innovations in construction contracts. *Transport Policy*, *47*, 119–126. https://doi.org/10.1016/j.tranpol.2016.01.004

Olsson Rader, A. (2009). Relational Rewards and Communicative Planning: Understanding Actor Motivation. *Planning Theory*, *8*(3), 263–281. https://doi.org/10.1177/1473095209104826

Ostrom, E. (1990). *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge University Press.

Ostrom, E. (2000). Collective Action and the Evolution of Social Norms. *Journal of Economic Perspectives*, *14*(3), 137–158. https://doi.org/10.1257/jep.14.3.137

Ostrom, E. (2005). *Understanding institutional diversity*. Princeton University Press.

Paddison, R., Docherty, I., & Goodlad, R. (2008). Responsible Participation and Housing: Restoring Democratic Theory to the Scene. *Housing Studies*, *23*(1), 129–147. https://doi.org/10.1080/02673030701731274

Palmer, D. E. (2015). No Title. Retrieved May 6, 2020, from https://www.britannica.com/topic/economic-rationality

Powell, W. W., & Colyvas, J. A. (2007). The New Institutionalism. In Stewart R. Clegg & James R. Bailey (Ed.), *International Encyclopedia of Organization Studies*. Sage Publishers.

Project Management Institute. (2013). *A Guide to the Project Management Body of Knowledge*. Project Management Institute, Inc.

Rip, A. (1992). A quasi-evolutionary model of technological development and a cognitive approach to technology policy. *Rivista Di Studi Epistemologici e Sociali Sulla Scienza e La Tecnologia 2*, 69–103.

Rip, A. (1995). Introduction of newtechnology: making use of recent insights from sociology and economics of technology. *Technology Analysis & Strategic Management*, *7*(4), 417–431.

Rip, A., & Kemp, R. (1998). Technological change. In S. Rayner & E. L. Malone (Eds.), *Human choice and climate change* (pp. 327–399). Battelle Press.

Ruonavaara, H. (2005). How Divergent Housing Institutions Evolve: A Comparison of Swedish Tenant Co-operatives and Finnish Shareholders' Housing Companies. *Housing, Theory and Society*, *22*(4), 213–236. https://doi.org/10.1080/14036090500375373

SCB. (2020). *Yrkesregistret med yrkesstatistik 2018 Yrkesstrukturen i Sverige*. (Statistiska Meddelanden AM 33 SM 2001), 29. Retrieved from https://www.scb.se/contentassets/b49d7efc2653457f8179f18461d2bf38/am0208_2018a01_sm_am33sm2001.pdf

Scharfstein, D. S., & Stein, J. C. (1990). American Economic Association Herd Behavior and Investment. *The American Economic Review*, *80*(3), 465–479. Retrieved from https://www.jstor.org/stable/2006678

Schot, J. (1992). The policy relevance of the quasi-evolutionary model: the case of stimulating clean technologies. In R. Coombs, P. Saviotti, & V. Walsh (Eds.), *Technological change and company strategies: economic and sociological perspectives* (pp. 185–200).

Schot, J. (1998). The usefulness of evolutionary models for explaining innovation. The case of the Netherlands in the nineteenth century. *History and Technology*, *14*(3), 173–200. https://doi.org/10.1080/07341519808581928

Schot, J., & Geels, F. W. (2007). Niches in evolutionary theories of technical change. *Journal of Evolutionary Economics*, *17*(5), 605–622.

Schot, J., & Geels, F. W. (2008). Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy. *Technology Analysis & Strategic Management*, *20*(5), 537–554.

SMHI. (2020). SMHI. Retrieved February 1, 2020, from https://www.smhi.se/vadret/vadret-i-sverige/risk-for-vattenbrist

Smith, A. (1776). *An Inquiry into the Nature and Causes of the Wealth of Nations.* Chicago: The University of Chicago Press.

Sorrell, S., Schleich, J., Scott, S., O´Malley, E., Trace, F., Boede, U., … Radgen, P. (2000). *Reducing barriers to energy efficiency in public and private organisations*. Retrieved from http://www.sussex.ac.uk/Units/spru/publications/reports/barriers/finalsection3.pdf

Sugden, R. (2000). Credible worlds : the status of theoretical models in economics. *Journal of Economic Methodology*, *7*(1), 1–31. https://doi.org/10.1080/135017800362220

Svensson, L., Ellström, P.-E., & Brulin, G. (2007). Introduction - On interactive research. *International Journal of Action Research*, *3*(3), 233–349.

Swedish Government Offices. (2018). *Sweden's draft integrated national energy and climate plan*. Retrieved from https://www.government.se/48ee21/contentassets/e731726022cd4e0 b8ffa0f8229893115/swedens-draft-integrated-national-energy-and-climate-plan

Swedish Parliament. *Utlåtande jämte utkast till lag med särskilda bestämmelser om vissa bostadsföreningar.* , Pub. L. No. 0375-250X; 1928:16 (1928).

Swedish Parliament. (1987). Co-operative society act. Retrieved from http://www.riksdagen.se/sv/Dokument-Lagar/Lagar/Svenskforfattningssamling/Lag-1987667-om-ekonomiska-f_sfs-1987-667/?bet=1987:667

Swedish Parliament. (1991). *Condominium Act*. Retrieved from http://www.riksdagen.se/sv/Dokument-Lagar/Lagar/Svenskforfattningssamling/Bostadsrattslag-1991614_sfs-1991-614/

Swedish Parliament. *Planning and building act.* , Pub. L. No. 2010:900 (2010).

Thollander, P., Palm, J., & Rohdin, P. (2010). Categorizing Barriers to Energy Efficiency : An Interdisciplinary Perspective. In J. Palm (Ed.), *Energy Efficiency* (pp. 49–63). Sciyo.

Trafikverket. (2018). *Trafikverkets arbete med produktivitet och innovation i anläggningsbranschen*. Retrieved from https://www.trafikverket.se/contentassets/faf06a1e99bf4024ab4e8680e9ed59aa/trafikverkets-produktivitetsarbete_slutversion.pdf

Tummers, L. (2015). Understanding co-housing from a planning perspective: why and how? *Urban Research & Practice*, *8*(1), 64–78. https://doi.org/10.1080/17535069.2015.1011427

Tversky, A., & Kahneman, D. (1971). Belief in the law of small numbers. *Psychological Bulletin*, *76*, 105–110.

United Nations. (2019). *World Population Prospects 2019: Highlights (ST/ESA/SER.A/423*. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12283219

Wahlgren, P. (2013). *Legal Risk Analysis: A Proactive Legal Method.* Stockholm: Facutly of Law Book Series.

Weber, L. (1997). Some reflections on barriers to the efficient use of energy. *Energy Policy*, *25*(10), 833–835.