Department of Real Estate, Planning and Geoinformatics

Evaluation of sustainability innovations in the construction sector

Juho-Kusti Kajander

Aalto University

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Juho-Kusti Kajander

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Abstract

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Abstract

The climate change mitigation market offers huge business opportunities for new construction services and products that improve sustainability in the built environment. In spite of the opportunities provided by sustainability, the construction sector is slow in producing innovations. Earlier studies suggest that the evaluation of innovation is a critical stage of the construction innovation implementation process and a major capacity development area for the whole sector. The aim of this research is to examine the evaluation of sustainability innovations in the construction sector as well as demonstrate managerial practises for the evaluation of sustainability innovations for construction companies.

The research utilizes a mixed-method research strategy. Both quantitative and qualitative data is collected and analysed with qualitative and quantitative methods to provide a more comprehensive understanding of the reseach topic. The study analyses sustainability innovations in the construction sector by using empirical data from innovation and construction projects.

This dissertation finds that construction companies can evaluate sustainability innovations by investigating their potential monetary benefits and makes the following proposals: (i) Construction companies should evaluate sustainability innovations together with clients and value networks to systematically manage the development and adoption of sustainability innovations; and (ii) construction companies can demonstrate the monetary benefits of sustainability innovations to shareholders with the event study method, and the benefits to clients and tenants with real option analysis. This dissertation presents and tests two new tools that construction companies can use to evaluate sustainability innovations.

Overall, this study contributes to the literature on construction innovation and to its practice by examining the evaluation of sustainability innovations in the construction sector. It does so by investigating the evaluation of sustainability innovations in construction projects and in the context of business management. Moreover, the present study demonstrates new managerial tools for the evaluation of sustainability innovations, i.e., event study and real option analysis.

The research experiences of the present study indicate that real option analysis has major potential as a tool for design target setting in construction projects, which represents a very interesting avenue for future research. More research is also needed to develop and to validate the use of the demonstrated tools for the evaluation of sustainability innovations in different empirical settings and with larger data sets. Finally, future research should establish a practical innovation evaluation theory for construction managers.

Keywords construction innovation, evaluation, decision-making, real option analysis, event study

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Tiivistelmä

Tekijä
Juho-Kusti Kajander

Väitöskirjan nimi
Kestävää kehitystä edistävien innovaatioiden arviointi rakennusalalla

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Tiivistelmä

Ilmastonmuutoksen hillintä tarjoaa merkittäviä liiketoimintamahdollisuuksia uusille rakennusalan palveluille ja tuotteille. Liiketoimintamahdollisuuksista huolimatta rakennusalan innovaatiotoiminta on hidasta. Aiemmissa tutkimuksissa innovaatioiden hyötyjen arviointi on tunnistettu keskeiseksi vaiheeksi rakennusalan innovaatioiden viemiseksi käytäntöön. Tämän väitöskirjan tavoitteena on tutkia miten rakennusalan yritykset voivat arvioida kestävää kehitystä edistäviä innovaatioita sekä yrityksen liiketoiminnassa että rakennushankkeissa. Lisäksi tutkimuksen tavoitteena on ehdottaa ja testata uusia työkaluja, joiden avulla rakennusalan yritykset, erityisesti urakoitsijat ja tuoteosavalmistajat, voivat arvioida kestävää kehitystä edistävien innovaatioiden taloudellisia hyötyjä.

Tutkimus perustuu mixed method -tutkimusstrategiaan, jossa sekä numeerista että laadullista aineistoa kerätään ja analysoidaan monipuolisesti laadullisilla ja kvantitatiivisilla menetelmillä. Tutkimuksessa käytetään empiiristä aineistoa rakennusalan yritysten innovaatiokäytännöistä ja -projekteista sekä rakennushankkeista, joissa hyödynnetään rakennusten käyttö- ja muuntojoustavuuteen, ilmanvaihtoon ja energiatehokkuuteen liittyviä innovaatioita.

Tämä väitöskirja osoittaa, että rakennusalan yritykset voivat arvioida kestävää kehitystä edistäviä innovaatioita kartoittamalla systemaattisesti niihin liittyviä taloudellisia hyötyjä ja epävarmuuksia. Tutkimuksen tuloksena väitetään, että i) rakennusalan yritysten kannattaa arvioida innovaatioita yhdessä tilaajan, käyttäjien ja kumppaniverkoston kanssa innovaatioiden kehittämisen ja käyttöönoton vauhdittamiseksi, ja ii) rakennusalan yritykset voivat arvioida innovaatioiden taloudellisia hyötyjä osakkeenomistajille event study -menetelmän ja tilaaja- ja käyttäjäorganisaatioille reaalioptioanalyysin avulla.

Väitöskirja edistää rakennusalan innovaatiotoiminnan tieteenalan tietämystä tutkimalla empiirisesti kestävää kehitystä edistävien innovaatioiden arviointia. Väitöskirjan tulokset parantavat innovaatioita koskevaa päätöksentekoa rakennusalalla korostamalla niiden taloudellisten hyötyjen arvioinnin merkitystä sekä liiketoiminnassa että rakennushankkeissa. Väitöskirjassa esitetyt ja testatut menetelmät ja niiden sovellukset auttavat rakennusalan yrityksiä arvioimaan innovaatioita käytännön päätöksentekotilanteissa.

Jatkossa kannattaa ehdottomasti tutkia tässä väitöskirjassa testattuja innovaatioiden arvioinnin menetelmiä laajemmalla aineistolla ja reaalioptioanalyysin hyödyntämistä rakennushankkeen kannattavuus- ja suunnittelutavoitteiden asettamisessa.

Avainsanat rakennusalan innovaatiot, arviointi, päätöksenteko, taloudellinen kannattavuus, reaalioptioanalyysi

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Each one of us is a product of all of our experiences and all our interactions with other people.

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Helsinki, August, 2016

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Papers of the dissertation

This doctoral dissertation consists of a summary and of the following six scientific publications, which are referred to in the text by their Roman numerals.

Paper I
Sivunen, M., Kajander, J.-K., Heinonen, J., & Junnila, S., 2011. ”Global challenges of sustainability business innovations in built environment.” *In the Proceedings of P. Huovila* (Ed.), *SB11 Helsinki - World Sustainable Building Conference*, October 18th - 21st 2011, Helsinki.

Paper II
Sivunen, M., Pulkka, L., Heinonen, J., Kajander, J.-K., & Junnila, S., 2013. “Service-dominant innovation in the built environment”, *Construction Innovation: Information, Process, Management*, Vol.13 Iss. 2, pp. 146-164. ISSN 1471-4175

Paper III
Kajander, J.-K., Sivunen, M., Vimpari, J., Pulkka, L., & Junnila, S., 2012. ”Market value of sustainability business innovations in the construction sector”, *Building Research & Information*, Vol. 40 Iss. 6, pp. 665-678. ISSN 0961-3218

Paper IV
Vimpari, J., Kajander, J. & Junnila, S., 2014. “Valuing flexibility in a retrofit investment”, *Journal of Corporate Real Estate*, Vol. 16 Iss. 1, pp. 3-21. ISSN 1463-001X

Paper V
Kajander, J-K., Sivunen, M., & Junnila, S., 2014. "Valuing Indoor Air Quality Benefits in a Healthcare Construction Project with Real Option Analysis", *Buildings*, Vol. 4 Iss. 4, pp. 785-805. ISSN 2075-5309

Paper VI
Vimpari, J., Sivunen, M., Kajander, J. and Junnila, S. 2014. “Risk management with real options in public private partnerships”, *CIB Internation- al Conference on Construction in a Changing World, Sri Lanka 3-7.5.2014.*

Author's contributions to the papers

The contributions of the author of this dissertation to the appended research papers I–VI is outlined below.

Paper I
Juho-Kusti Kajander shared the responsibility for initiating, executing and writing the paper with Matti Sivunen. Seppo Junnila provided valuable comments and suggestions on the paper.

Paper II
Juho-Kusti Kajander had the primary responsibility for developing the theoretical framework. Matti Sivunen had the primary responsibility for executing and writing the paper. Lauri Pulkka was responsible of data analysis. The other co-authors provided valuable comments and suggestions to make the paper better.

Paper III
Juho-Kusti Kajander had the primary responsibility for initiating, executing and writing the paper. The co-authors provided valuable suggestions and comments to make the paper better. The editor of the journal *Building Research & Information* rewarded the paper with title "recommended paper of the year 2012".

Paper IV
Juho-Kusti Kajander shared the responsibility for initiating, executing and writing the paper with Jussi Vimpari. Seppo Junnila provided valuable comments and suggestions on the paper.

Paper V
Juho-Kusti Kajander had the primary responsibility for initiating, executing and writing the paper. Matti Sivunen was responsible for cost analysis and Seppo Junnila provided valuable suggestions and comments to make the paper better.

Paper VI
Juho-Kusti Kajander shared the responsibility for initiating, executing and writing the paper. Seppo Junnila provided valuable comments and suggestions on the paper.

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1 Introduction

1.1 Motivation and background

Climate change mitigation is one of the greatest challenges facing society (UNEP, 2007; IPCC, 2014). It has led to the emergence of the fastest growing new investment market in the world with over US$300 billion in investments annually (Bloomberg New Energy Finance, 2016). Inside the climate mitigation market, the construction sector is assessed to offer a wide scope of opportunities for new cost-effective services and products that improve sustainability in the built environment (McKinsey & Co., 2009). According to ISO definition (ISO 15392, 2008) sustainability refers to a state in which the components of the environment and their functions are maintained for present and future generations. In the construction sector, sustainability relates to how the attributes of the activities, products or services used in construction work, or the use of the construction works, contribute to the maintenance of ecosystem components and functions for future generations (ISO 15392, 2008). Constructing buildings that have the capacity to adapt over time to changing uses and preferences with minimal conflict is an example of sustainability in construction (Kendall, 1999).

In particular, the situation calls for fast customer-oriented innovations as the time frame for corrective actions is short, specifically in the construction sector, e.g., to produce almost zero energy buildings by the year 2021. Moreover, renewal in the construction sector has huge economic importance, because the built environment accounts for more than 20% of gross domestic product (GDP) and 50-60% of gross national wealth in most countries.

Paradoxically, in spite of the sustainability opportunity, the rate of innovation in the construction sector lags behind most other industries (e.g., Winch, 1998; Slaughter, 2000; Dubois & Gadde, 2002; Seaden et al., 2003; Bygballe & Ingemansson, 2014). In practice, there is an urgent need for research to understand how sustainability innovation is currently managed in the construction sector and to develop means to speed up the up the innovation process. The present study is an attempt to address this need and to make a contribution to the construction innovation literature. Here the construction sector is the segment of the economy in which companies operate in the business of continuous asset, property, and facilities management, as well as in transaction services, project management, on-site production activities, manufacturing, distributions, and regulation (Carassus, 2004). Moreover, in the context of this research innovation refers to new products, processes, or systems that contain substantial and non-trivial improvements to existing products, processes, or systems, and that are actually used by a company (Slaughter, 2000).

Classical economics literature on innovation has shown that innovation is a primary source for economic growth (e.g., Schumpeter, 1942; Solow, 1956; Schmookler, 1966; Freeman, 1974; Scherer 1982) and company competitive advantage (e.g., Barney, 1986; Bettis & Hitt, 1995; Teece, 2007) in market economies. Moreover, companies can improve profitability through innovation (e.g., Griliches, 1957; Schmookler, 1966; Baumol 1993). Earlier construction innovation studies suggest that also in industry innovations can improve the competitive advantage and profitability of companies (Johnson and Tatum, 1993; Slaughter, 2000; Barlow, 2000; Miozzo and Dewick, 2002; Seaden et al., 2003; Zimina et al., 2012; Bock & Linner, 2015). For example, a new design or technology may be the means through which a company can achieve the client's objectives for a set of projects and improve the performance of a facility. In addition, an innovative reputation can increase the potential market for a construction company, particularly in higher value or performance projects (Slaughter, 2000).

The construction sector has characteristics that affect the innovation process and the economic incentives to invest in innovation (Miozzo and Dewick, 2002; Manley, 2008; Whyte and Sexton, 2011; Bygballe & Ingemansson, 2014). First, construction is a project-based business. Consequently, innovation adoption decisions and implementation are carried out in construction projects, which are often unique and uncertain (Winch, 1998; Slaughter, 2000). Second, the one-off nature of most building projects seems to limit the degree to which a given innovation will be applicable to other situations, reducing the benefits of innovation and therefore incentives to innovate from the perspective of construction companies (Barlow, 2000; Miozzo and Dewick, 2002). Typically, a firm will have the incentive to adopt an innovation only if it can later obtain a return on investment that justifies the uncertain investment involved with the development and adoption of the innovation (Winch, 1994, Hall, 2004). Third, a construction project involves multiple stakeholders – e.g., clients, tenants, project-based firms and suppliers – with different business models (Bygballe & Jahre, 2009). Therefore, innovation implementation in construction projects often requires extensive negotiations and a gain-sharing approach among multiple organizations to reach a common understanding and change practices in a coordinated way (Winch, 1998, Sheffer & Levitt 2012). Fourth, firms have to rely on the relationship with clients and the capabilities of clients and value network to produce innovations (Blayse and Manley, 2004). In particular, previous construction innovation literature has recognized the key role of the end customer, i.e. the client, the person or firm responsible for commissioning and paying for the construction project (Anumba et al., 1996). For example, clients can identify specific novel requirements to be supplied by developers, contractors and by manufacturing companies (Seaden & Manseau, 2001, Blayse & Manley, 2004), they can integrate knowledge across organizations (Barlow, 2000) and they can influence the way in which a construction project is carried out (Rose & Manley, 2011; Pekuri et al., 2014). As the requirements related to building design and performance increase constantly, close connections to clients, investigation of client needs, and the utilization of client feedback in the management, design and development of new services and products are essential for construction innovation (Bock & Linner, 2015).

Earlier construction innovation research has identified the evaluation of innovation in construction projects as a critical stage of the construction innovation implementation process (Winch, 1998; Mitropoulus & Tatum, 1999; Slaughter, 2000). At the evaluation stage the basis for the decision to invest is prepared through scanning external and internal information on the innovation, and the evaluation of the potential costs and benefits of innovations is carried out in respect to specific project targets, such as financial targets, building qualities and long-term facility performance and risks (Slaughter, 2000). In particular, an explicit investigation of the potential benefits of an innovation is critical at this stage is to reveal the full range of benefits of the innovation to the stakeholders of the construction project (Winch, 1998; Slaughter, 2000). However, while investment decisions on construction projects in practice are typically based on feasibility studies, it is exceptional that, for example, the economic benefits of new design and technological solutions are evaluated in construction projects. For example, building investment feasibility studies and project documents do not typically contain quantitative analysis of life-cycle economic benefits and costs of design solutions (Elf & Malmqvist, 2009; Zimina et al., 2012). Moreover, the decision-making on the adoption of new technologies is not typically a systematic process in construction companies and the justification of investments is typically based on intuition rather than the analysis of benefits and costs (Mitropoulos & Tatum, 1999). According to Slaughter (2000), companies considering the initial use of an innovation need a systematic approach to identify the activities that can reduce avoidable uncertainty and risk, and increase the effectiveness of the planned innovation use.

While the research area of evaluating construction innovation has been established, there seems to be a lack of knowledge and a need for studies (Winch, 1998; Slaughter, 2000) that address the topic both qualitatively and quantitatively in the setting of real life construction projects, where the investment decisions for construction innovation need to made systematically, rapidly and with limited, ambiguous and incomplete data. This research direction has also been recognized as a major capacity development area for construction companies and the whole sector (Winch, 1998; Slaughter, 2000).

In this context, this dissertation focuses on examining the evaluation of sustainability innovations in the construction sector, i.e., on new services and products that aim to improve sustainability and contain substantial and non-trivial improvements that are actually used in real life, and that are specifically associated with the design, construction and use of built facilities. Innovation is an essential activity for utilizing the capacity of companies to solve the climate change challenge and to introduce new products and services to the market (Rennings, 2000). However, the construction sector does not seem to produce innovations with a speed that can be expected of a modern industry despite the sustainability opportunity. This dissertation investigates how construction companies can evaluate sustainability innovations in the context of company innovation projects and construction projects. The evaluated sustainability innovations in the present study include cases of physical flexibility, modifiable ventilation capacity and a building integrated ground heat system. In the context of this work a “construction company” is defined as an organization performing some of the following functions of building construction: project development, project management, design and engineering, on-site production activities and manufacturing.

This dissertation contributes to the literature of construction innovation. In particular, this research is motivated by, and continues the work of Slaughter (2000) on systematic approaches to evaluate innovations in real life decision-making situations in the construction sector. Slaughter's (2000) conceptual model for planning the use and implementation activities of construction innovations in construction projects is described in more detail in Chapter 2.4. The present study adds new knowledge to the model by investigating how construction companies can evaluate sustainability innovations.

1.2 Research objectives and research questions

The business opportunity for sustainability innovations is huge in the construction sector, yet the production of sustainability innovations in construction has been slow. The aim of this research is to examine the evaluation of sustainability innovations in the construction sector, as well as to demonstrate managerial practices for the evaluation of sustainability innovations for construction companies. The purpose of the research is to increase knowledge on the evaluation of sustainability innovation in the construction sector.

This dissertation has two research questions that address the evaluation of sustainability innovations in the construction sector from the innovation development and adoption perspectives. With the first research question, the focus is on the evaluation of sustainability innovation development activities of construction companies. The focus is limited to the evaluation of client and value network engagement, and shareholder value relevance of construction company driven sustainability innovation projects as earlier studies (e.g., Barlow, 2000; Seaden & Manseau, 2001; Miozzo & Dewick, 2002; Blayse & Manley, 2004; Bygballe & Ingemansson, 2014; Bock & Linner, 2015) suggest that construction companies rely on clients and value network to produce innovations.

RQ1: How can construction companies evaluate their sustainability innovation development?

The second research question addresses the evaluation of the potential monetary benefits of sustainability innovations in the investment feasibility evaluation phase of construction projects through real option analysis. The focus is on construction projects, as earlier construction innovation literature (Winch, 1998; Slaughter, 2000) has identified that construction innovations are implemented in projects, and that the evaluation of innovation is a key stage of the innovation implementation process that can be used to reduce avoidable uncertainty and risk and increase the effectiveness of innovation use. Moreover, real option analysis (ROA) is a promising investment decision-making approach, in which embedded options, such as flexibility and adaptability in real asset investments are valued using option pricing techniques that originate from the financial world. Earlier studies (e.g., de Neufville, 2003; Greden & Glicksman, 2005; van der Maaten, 2010; Vimpari & Junnila, 2015) suggest that ROA has great potential to enhance decision-making in the construction sector. In this vein, the second research question which this research aims to answer is:

RQ2: How can construction companies use real option analysis to evaluate sustainability innovation investments in construction projects?

In the next section the structure of this work is presented in detail.

1.3 Structure of this dissertation

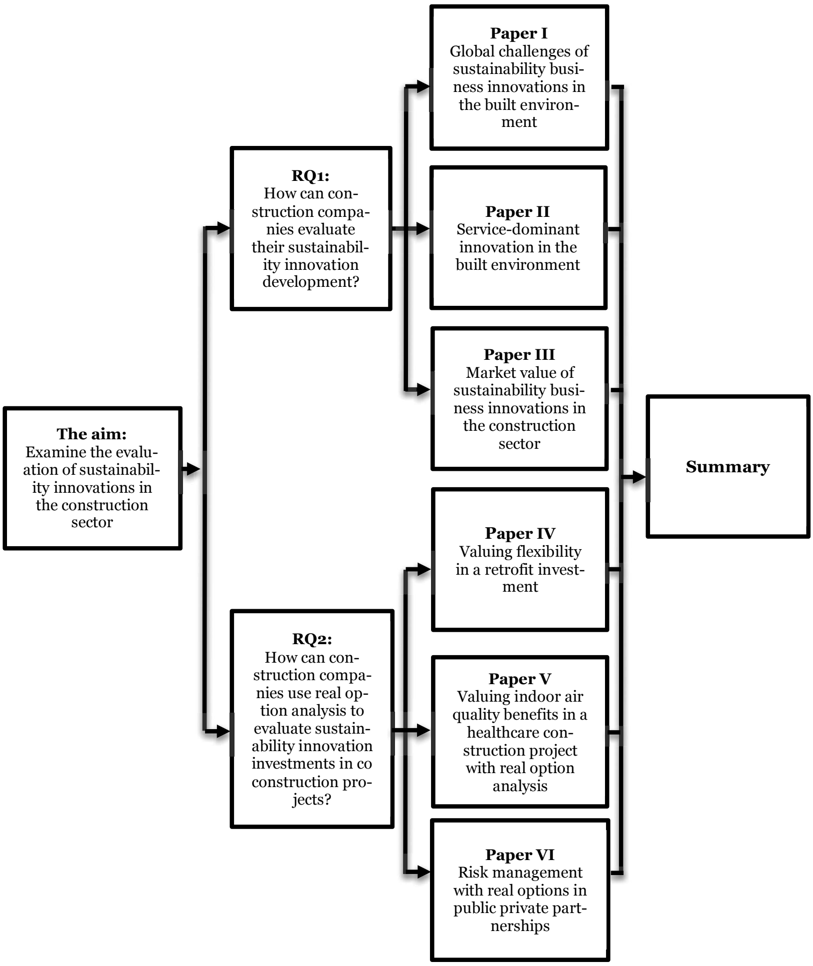

Figure 1. Research structure

The dissertation consists of four appended articles that have been reviewed and published in academic journals and two appended articles that have been reviewed and published in scientific conference publications. All of the articles study the evaluation of sustainability innovation in the construction sector (see Figure 1) and all the data in the articles are related to sustainability innovation in the construction sector. In Papers I, II and III the research focus is on studying construction company driven sustainability innovation projects and the evaluation of the innovation production of these projects in terms of client and value network engagement, and shareholder value relevance. Papers IV, V and VI examine how ROA can be used to evaluate sustainability innovations in construction projects. The data of the present study is presented in Chapter 1.4 and the theoretical background is summarized in Chapter 2.

Paper I investigates the challenges of sustainability innovation in the construction sector. The purpose of Paper I is to provide an overview of the current challenges of sustainability innovation in the construction sector.

Paper II examines how company driven sustainability innovation projects utilize customer-oriented innovation models through a survey of sustainability innovation projects.

Paper III examines the connection between sustainability innovation announcements and the market value of publicly listed companies in the construction sector. Innovation announcements and company financial data were collected and analyzed with an event study model.

Papers IV, V and VI focus on investigating and demonstrating new practices for the evaluation of potential monetary benefits of sustainability innovation in construction projects. Papers IV, V and VI are case studies that explore how ROA can be used for evaluating the potential monetary benefits in real life construction projects and present research processes for the evaluation. The evaluated sustainability innovations included physical flexibility, modifiable ventilation system, and a building integrated ground heat system. The case organizations were public sector property owners including the largest property owner in Finland, and tenant organizations, i.e., an administration and a health care organization. The types of premises varied from offices to basic health care premises and the types of projects from retrofit to new building.

The summary integrates the findings of the papers.

1.4 Research methodology and data sources

This research utilizes a mixed method research strategy with both quantitative and qualitative data (Creswell, 2014). Mixed methods research is an approach to research in which the investigator gathers both quantitative and qualitative data, integrates the two, and then draws interpretations based on the combined strengths of both sets of data to understand research problems (Cresswell, 2014). Mixed methods can be seen as a relatively new methodology originating from around the late 1980s and the early 1990s based on work of individuals in diverse fields such as evaluation, management, sociology, evaluation and health sciences (Cresswell, 2014). Mixed methods strategy was selected for the present study because it enables to obtain a more comprehensive understanding about the problem by seeing the problem from multiple angles and multiple perspectives. Moreover, the study has several characteristics of pragmatism, which is typical for mixed method studies (Creswell & Plano Clark, 2011).

The research design of the dissertation is convergent design. Convergent design involves the separate and parallel collection and analysis of quantitative and qualitative data. The intent is to bring together and to compare the results of quantitative and qualitative analysis to gain multiple pictures of the research problem from several angles (Creswell & Plano Clark, 2011; Cresswell, 2014).

Convergent research design has four main phases (Creswell & Plano Clark, 2011, Cresswell, 2014). First, quantitative and qualitative data are collected separately and concurrently. They have equal importance in addressing the study's research questions. Second, the two data sets are independently analyzed by typical quantitative and qualitative analytical procedures. Third, after the results have been compiled, the interpretation of the results of the two databases are brought together and directly compared in a discussion. In the final step, the study interprets the extent to which and the ways in which the two sets of results converge and can be combined to create better understanding in response to the study's overall purpose, and to which extent the two sets confirm the results of each other. Phases one and two are presented in each appended research paper and steps three and four are presented in the summary part of the dissertation.

The key challenges of convergent design are the need for versatile research expertise, parallel construction of datasets, and successful merging of the dataset (Creswell & Plano Clark, 2011; Cresswell, 2014). First of all, the researcher needs to master the research area and both qualitative and quantitative research methods to perform mixed methods research. To manage this challenge, the research was conducted together with several co-authors, who have a deep understanding of and strong expertise in the construction sector, innovation, financial analysis, sustainability, data collection and analysis. Second, due to the concurrent timing of building the qualitative and quantitative datasets, the mixed method researcher needs to start with the same measures/assessments with both quantitative and qualitative data in order to merge the results. This challenge was addressed by reviewing the state-of the-art and following that by designing the data collection and analyses so that they addressed the same concept. Finally, the researcher needs to know how to merge the databases, and hence, be familiar with side-by-side comparisons. To overcome this challenge, the compiled results from the two datasets were carefully weighted and interpreted.

The research approaches of the articles included in this dissertation were selected based on the nature of the research problems and the aim of the research (Creswell & Plano Clark, 2011). Paper I employed semi-structured interviews to uncover the interviewees' meanings in respect to sustainability innovations in the construction sector and to give freedom in the sequencing and wording of questions as a result of the interviewees' responses (Robson, 2002). A framework was created to structure the empirical analysis of innovation projects in Papers II and III. The framework was called the sustainability business innovation (SBI) framework to underline the centrality of commercially viable solutions as a response to the sustainability challenge. The framework was originally presented by Kajander et al. (2010). The framework was based on service-dominant (S-D) logic (Vargo and Lusch, 2004). The S-D logic approach provides a customer-centric view for evaluating, managing and developing innovation processes. According to S-D logic (Vargo & Lusch, 2004), the value of the innovation is co-created with the client during the innovation process, rather than embedded in the output of the process. The framework comprises three components; discontinuity of innovation, active customer participation and value network involvement. The premise of the framework is that an effective and efficient innovation process is based on customer and value network involvement and ambitious discontinuous innovation targets. Active customer participation is beneficial for innovation, because it enables companies to target their development efforts according customer needs and value. Furthermore, value network involvement enables companies to reduce the need for in-house technological and business expertise, and ensures that external ideas and resources are used in the development project. The discontinuity of innovation is one of the components, because instead of incremental steps, businesses should aim to make radical leaps in new products and services. Discontinuity is particularly relevant for sustainability innovation due to the short-time frame for corrective actions. The SBI framework is discussed in detail in Paper II.

To deepen our understanding of the findings and to obtain quantitative evidence for the comparison of the findings in the qualitative study, a survey was used in Paper II (Robson, 2002). In Paper III, the event study method was selected since the aim of the study was to measure the market capitalization impact of a specific event (Fama, 1998), sustainability innovation announcements of construction companies. Papers IV, V and VI utilized the single case study method (Yin, 2014) to understand how ROA, specifically the pay-off method, can be used for the evaluation of sustainability innovation investments in construction projects. The aim of the case studies is to acquire a deep understanding of the nature, importance, and functioning of one or a few cases, and to report this understanding thoroughly, carefully, and credibly to the scientific audience (Lukka & Kasanen, 1995).

In this dissertation, the data was collected from four main sources: literary resources (academic publications, research reports, financial reports, construction project documentation, and industry news), expert interviews and workshops, and a survey. In general, quantitative data was used to statistically analyze client and value network engagement, and shareholder value relevance of sustainability innovation. In the case studies, quantitative data was used to demonstrate the quantification of the potential monetary benefits sustainability innovation investments with ROA. Moreover, qualitative data was used to understand the studied phenomenon from the stakeholder perspective, and to perform the case studies at the construction project level. The choice of data sources in each paper reflected the aim of the research. In Paper I, 11 semi-structured interviews of senior managers of construction companies and venture capital investors were conducted and analyzed. In Paper II, 44 sustainability innovation projects in the construction sector were analyzed. Three datasets were constructed for Paper III, i.e., construction company market data, sustainability innovation announcements of construction companies, and data from four workshops. The main data sources for Paper IV were an investment case, government employee projections and 3 workshops. Papers V and VI utilized investment case data, project briefing documentation and data from the workshops of a healthcare building project.

The research papers, research method, research approach and data are summarized in Table 1.

Table 1. Research methods, research approaches and main data sources used in the papers

Paper	**Research method**	**Research approach**	**Main data Sources**
Paper I	Qualitative	Semi-structured interview study	11 interviews with Finnish and international innovation professionals
Paper II	Quantitative	Survey study	A survey of 44 innovation projects, workshops
Paper III	Quantitative	Event study	30 innovation announcements, company and market data, workshops
Paper IV	Qualitative	Single case study, real option analysis	Investment case, government employee projections, workshops
Paper V	Qualitative	Single case study, real option analysis	Investment case, project briefing documentation, workshops
Paper VI	Qualitative	Single case study, real option analysis	Investment case, project briefing documentation, workshops

2 Theoretical background

This chapter presents the theoretical background of the dissertation. The aim of this chapter is to briefly describe the main theoretical principles that have motivated and inspired the research process and, moreover, to identify the contribution of the dissertation to the existing literature. Additional information can be found in the appended articles.

This study is linked to the academic discussion on the management of innovations that enhance sustainability in the construction sector. The Chapter summarizes the theoretical foundation of the present study from the following perspectives: drivers of innovation, innovation processes, evaluation of the economic value of innovation investments, construction innovation and the economic value of sustainability innovation in the construction sector. Finally, the theoretical background of the dissertation is summarized.

2.1 Drivers of innovation

According to classical economics literature (e.g., Schumpeter, 1942; Solow, 1956; Schmookler, 1966; Freeman, 1974; Scherer, 1982) innovation is a primary source of rapid economic growth achieved by industrialized nations. Moreover, innovation is a key component of company competitive advantage in market economies (e.g., Barney, 1986; Bettis & Hitt, 1995; Teece, 2007). Innovation research accelerated in the 1940s and 1950s as Schumpeter (1942) described innovation through the process of creative destruction and Solow (1956) established the importance of innovation to economic growth.

Companies innovate to improve their financial performance. Companies can gain above-average profits through the competitive advantage created by innovation (e.g., Smith, 1776, p. 63-64, Baumol, 1993). However, as competition between firms tends to decrease above-average profits over time

(Smith, 1776, p. 62), firms need to constantly enhance their competitive advantage and profitability (Teece, 2007). Moreover, innovation can have a positive impact on the stock market value of company (e.g., Chaney et al. 1991; Sood & Tellis 2009) as the market valuation of a company should be a forward looking indicator of firm performance (Hall et al., 2005).

Earlier innovation research suggests that market demand is the key driver and source of innovation (e.g., Di Stefano et al., 2012). The larger the potential market is, the more innovation activity will be directed toward it (Schmookler, 1966). Changes in market conditions such as relative factor prices (Hicks, 1932) and customer problems (Rosenberg 1969), geographic variation in demand (Griliches, 1957), and potential new market opportunities (Vernon, 1966) affect the pay-off of investments in innovation.

In addition to market demand, science and technology, and governmental regulations can also have a considerable effect on the magnitude and direction of innovative activity. Advances in scientific understanding and technology can bring about technological innovation (e.g., Nemet, 2009; Di Stefano et al., 2012) particularly when coupled with a market opportunity. Freeman (1974) found that successful innovations couple technical opportunity with a market opportunity for example through experimental development and design, trial production and marketing. Moreover, governments can influence innovation activity for example through market pull and technology push policies that alter private costs and pay-off of innovation (Nemet, 2009). Importantly Pavitt (1984) showed that industry specific attributes significantly affect the relative importance of each driver of innovation.

2.2 Innovation processes

Several scholars have studied and described innovation through process models at the company level, i.e., how firms match technology with demand and capitalize on technology and demand as sources of innovation and commercialize the results successfully (e.g., Di Stefano et al., 2012). Research within this literature stream has been inspired by three research domains – new product development processes, open innovation, and service-dominant logic – which will be briefly discussed in the following. A number of studies have researched new product development (NPD) processes, which typically focus on the management of in-house R&D, manufacturing and marketing

(Zirger & Maidique, 1990), and are characterized by extensive process planning and operations under secrecy (Chesbrough, 2003a, 2003b, 2004; Michel et al., 2008). The stage-gate model is a well-known NPD process that applies process management practices to innovation processes (e.g., Cooper, 1990, 2005, 2007). In the stage-gate model, product ideas are submitted for technical and market assessment. After a preliminary elimination phase, the surviving ideas are transferred to a detailed investigation. Following that, a decision on the business case is made and feasible ideas continue to the next stages, i.e., development, testing and validation, and full production and market launch. Every stage is followed by a control checkpoint.

An increasing number of companies make greater use of external ideas and technologies in their own business, and let unused internal ideas and technologies go outside for others to use. Henry Chesbrough described and named this innovation process ”open innovation” (Chesbrough, 2003a), which has since become a highly popular concept in innovation research. The basic premise of open innovation is that the sources of knowledge for innovation are widely distributed in the economy and hence firms should open up the innovation process to benefit from this knowledge (Chesbrough & Bogers, 2014). Only recently Chesbrough and Bogers (2014) re-defined open innovation as a distributed innovation process based on managed knowledge flows across organizational boundaries, using monetary and non-monetary mechanisms in line with the organization's business model. In this definition, innovation refers to the development and commercialization of new or improved products, processes or services, while the openness aspect is represented by the knowledge flows across the organizational boundary (Chesbrough & Bogers, 2014). Key company processes for the implementation of open innovation include strategic decision-making, seeking opportunities and evaluating their market potential, establishing partnerships and developing a diverse partner base, capturing value through commercialization, and balancing incentives and controls (Huizingh, 2011).

The S-D logic approach provides a customer-centric view for evaluating, managing and developing innovation processes. According S-D logic (Vargo & Lusch, 2004), the value of an innovation is co-created with the client during the innovation process rather than embedded in the output of the process. Hence, innovation development should always be strategically targeted at a specific client’s need. Moreover, Lusch et al. (2010) argue that integrating the innovator’s value network is an imperative asset in the innovation process. Value network integration enables the effective management of some of key questions related to the development of innovation, such as what is the most effective way to involve suppliers and clients in the design process of services and how to coordinate the value network to speed up the innovation process. In summary, the S-D logic approach highlights the importance of strong client participation and value network involvement in a successful innovation process.

2.3 Evaluation of the economic value of innovations

Whether or not to invest in the development or adoption of an innovation is a fundamental question for most firms. The literature on the evaluation of the economic value of innovations has addressed this topic and will be briefly reviewed in the following as it has considerably inspired the present study.

A number of studies have researched innovation investment decision-making, and suggest that innovation investment decisions are made under high uncertainty. In market economies, a firm will primarily have an incentive to invest in new services and products only if it can later obtain profits that justify the initial investment (Schmookler, 1966; Winch, 1994). Stoneman (2001) argues that the decision to develop or adopt innovations is fundamentally an investment decision made in an uncertain environment. In effect, the benefits from adopting a new technology are received during the life of an innovation and, in contrast, the costs are typically incurred at the time of adoption and cannot be recovered (Hall, 2004). Therefore, as in the case of the investment decision, the adoption of innovation is characterized by uncertainty over future profit streams, irreversibility that creates at least some sunk costs, and the opportunity to delay. According to Encaoua et al. (2013), the uncertainties that are associated with the use, development, and marketing of an innovation can be divided into the three classes. First, technological uncertainty refers to the fact that companies that have committed resources to research and development activities are never sure beforehand that they possess the expertise necessary to transform the research and development results into a technologically viable service or product. Second, strategic uncertainty arises from the fact that a company developing an innovation is never sure of being the first to introduce the innovation to the market. Finally, market uncertainty refers to the fact when a company commits to an innovation project it cannot be sure that sufficient market demand for the innovation exists at the time of market introduction.

In particular, innovation adoption decisions seem to be primarily based on a comparison of the uncertain life-cycle benefits of the innovation with the uncertain total costs of adopting it, and information about innovation (Hall, 2004). Especially uncertainty about benefits, costs, or length of life seems to slow the rate of innovation adoption (Hall, 2004), also in the case of sustainability enhancing innovations (Allan et al., 2014). Developers of an innovation can reduce this uncertainty and influence the adoption decision through disclosing relevant information about the attributes of the innovation. For example, Rogers (2003) has classified the attributes that influence the potential adopters of an innovation to five classes; 1) the relative advantage of the innovation; 2) its compatibility with the potential adopter's current way of doing things and with social norms; 3) the complexity of the innovation; 4) trialability, i.e., the ease with which the innovation can be tested by a potential adopter; and 5) observability, i.e., the ease with which the innovation can be evaluated after trial. Obviously other factors such as market size, industry environment and structure, and cultural and social determinants strongly influence the adoption of innovations (Hall 2004).

Finding and investing in innovations that are valuable is an important and challenging task for companies (Koen et al., 2002). Innovation selection is challenging because decisions have to be made in a short timeframe, and available information is typically incomplete and ambiguous (e.g., Eisenhardt, 1989; Collan & Kinnunen, 2011; Cousins et al., 2011). Moreover, the return on investment for innovations is difficult calculate beforehand as the benefits are expected to spread over many phases of the firm's activities and to stretch into the distant future (Kasanen, 1993).

In practice, companies perform innovation scanning, screening and evaluation to prepare innovation investment decisions (Deschamps, 2009; Cousins et al., 2011 Farrukh et al., 2013). Scanning refers to the investigation of innovations new to the industry or outside the traditional industry boundary, and a general preference to explore new knowledge (Cousins et al., 2011). Screening refers to the process of selecting a few investment opportunities out of a larger set of scanned opportunities for a deeper pre-investment analysis before making a final investment decision (Brown & Campion, 1994; Metrick & Yasuda, 2011; Collan & Kinnunen, 2011; Chan & Park, 2015). According to Farrukh et al. (2013) the evaluation of the potential economic value of an innovation has three key steps; 1) exploring the opportunities of new technologies; 2) quantification of the potential return of innovation; and 3) communicating with the stakeholders of the innovation in order to reach a common understanding of assumptions and approach (Farrukh et al., 2013). Moreover, according to Farrukh et al. (2013) the evaluation of the innovation should be done jointly with customers and stakeholders through a numerical and visual business case to facilitate the adoption of the innovation.

There are several qualitative and quantitative methods available to evaluate the potential economic value of an innovation (Henriksen & Traynor, 1999; Verbano & Nosella, 2010; Farrukh et al., 2013). The most popular economic evaluation method is discounted cash flow (DCF) analysis, which is relatively easy to use (Farrukh et al., 2013). However, several studies suggest that DCF based evaluation systems are incapable of evaluating investments that are highly uncertain and take place far ahead in the future (e.g., Sharp, 1991; Trigeorgis, 1993; Trigeorgis, 1996). It seems that DCF cannot capture the value of future opportunities under high uncertainty, because it ignores the value of the flexibility of the innovation (Dixit & Pindyck, 1995; Trigeorgis, 1996; Scarso, 1996). Of the many evaluation methods available, the present study concentrates on a method called real options analysis (ROA). ROA has been proposed as a promising method to evaluate the economic value of highly uncertain investments in innovation. (Chesbrough, 2003a; Vanhaverbeke et al 2008; Collan, 2011; Farrukh et al., 2013).

ROA is an approach that is often considered to supplement the popular DCF analysis when evaluating investments in real assets. In ROA, embedded options in real asset investments are valued using option pricing techniques originating from the financial world. The most widely known techniques to solve the option value are the Black-Scholes equation, binomial option pricing model and the Monte Carlo method (Amram & Kulatika, 1999). In all of the methods, the option value is calculated by determining the range of values of the underlying asset. The key component in determining the range is finding out the volatility of the asset. This has been relatively straightforward in the original applications of finance where detailed historical data has been available. However, with real assets this is often very challenging. ROA has received criticism (e.g., Lander & Pinches 1998; Oppenheimer, 2002) for this exact reason, even though the practical applicability of the approach has been well acknowledged. Recently the calculus related to valuing real assets with ROA has become more straightforward. For example, in the fuzzy pay-off-method (FPOM) only 3 pay-off scenarios (minimum, best guess, maximum) are needed for investment valuation (Collan et al., 2009). Option value can then be calculated simply with a typical spreadsheet. In the context of the pay-off method, the real option value is the possibilistic mean of the positive side of the value terrain weighted by the positive area of the pay-off distribution over the whole area of the pay-off distribution (Collan et al., 2009).

The context of the FPOM is possibilistic, that is, the evaluations are considered to be normative judgments and not probability distributions. The inspiration for the FPOM originally came from the Datar-Mathews method (Datar and Matthews, 2004), which calculates the real options value from the pay-off distribution of net present values (NPV) generated by Monte-Carlo simulations. Collan et al. (2009) realized that the probabilistic theory used in the Datar-Mathews method (and in other mainstream ROA methods) to treat for uncertainty could for modeling purposes be replaced with the fuzzy set theory (Zadeh, 1965). In the fuzzy set theory, different propositions have a degree of membership in a set, i.e., the membership is 0 (complete non-membership), 1 (complete membership) or a value between 0 and 1 (an intermediate degree of membership). This realization allowed a simplification of the projection of uncertainty from three NPV scenarios: minimum, best guess (i.e., the most likely scenario, which is normally drawn up in investment analysis) and maximum. These three scenarios are treated as triangular fuzzy numbers that form a triangular pay-off distribution where the best guess scenario has complete membership, the minimum and maximum scenarios have complete non-membership, and other scenarios in-between have intermediate degrees of membership. The NPV from these three scenarios is used as the basis for the creation of a triangular fuzzy number that is interpreted as a (simplified) fuzzy representation of the uncertain project net present value (Collan et al., 2009).

An increasing number of studies apply ROA to assess the economic feasibility related to sustainable building investments. In the field of ventilation systems, Greden et al. (2006) applied ROA to evaluate the profitability of an innovative HVAC system. In a case study, the option to switch a naturally ventilated building into a mechanically ventilated building was examined with ROA. In addition, ROA studies have examined the profitability of solar collectors (van der Maaten, 2010), space flexibility and modifiability (de-Neufville, 2003; Greden & Glicksman, 2005) and green building certificates (Vimpari & Junnila, 2014).

2.4 Construction innovation

Construction innovation literature has emerged to study innovation in the construction sector. The definitions for construction innovation differ particularly in terms of business orientation. Construction innovation has been defined merely as a design solution for a building (Toole, 1998). In contrast, for example Slaughter (2000) and Seaden et al. (2003) define construction innovation as new products, processes, or systems that contain substantial and non-trivial improvements and that are actually used by a company. Moreover, the aim of construction innovation is to enhance company efficiency (i.e., improved quality, lower production costs) and/or effectiveness (i.e., greater market share, client satisfaction) (Seaden et al. 2003). The present study understands construction innovation in the line of Slaughter (2000) and Seaden et al. (2003).

Innovations in the construction sector diffuse slowly (Winch, 1998). The construction sector has distinctive characteristics that affect the innovation process; value networks are complex by nature, activities are project-based and regulated (e.g., Winch, 1998; Miozzo & Dewick, 2002; Dewick & Miozzo; 2004, Toole et al., 2013; Bygballe & Ingemansson, 2014). The slow rate of innovation diffusion can be attributed to an industry characterized by extreme fragmentation and technological risk aversion due long time horizons and high capital costs (Sheffer & Levitt 2010). Moreover, the culture of low cost competitive bidding and principal and agent problems slow down innovation diffusion (Sheffer & Levitt 2010). Moreover, a considerable share of construction innovations are systemic innovations that require multiple firms in a network to change practices in a coordinated way (Sheffer & Levitt 2012).

Clients can have a considerable effect on construction innovation. The end customer of the construction company, i.e., the client, person or a company, is responsible for commissioning and paying for the construction project (Anumba et al., 1996). Clients are a versatile group, which differ for example in terms of their experience and expertise, and business model. For example, investors are usually seeking short-term returns while user-owners usually have a longer investment horizon with broader scope of targets (Barlow, 2000). Clients' role in construction innovation is highlighted, as they specify the requirements for building performance and for project participants (Seaden & Manseau, 2001, Blayse & Manley, 2004), generate trust and collaboration between project participants (Bygballe and Ingemansson, 2014), and often carry a number of the risks associated with the innovations (Nam & Tatum, 1997). Clients can have a considerable positive effect on construction innovation (Gambatese and Hallowell, 2011) particularly in the case of public sector clients with innovative demands (Bossink, 2004). In addition, client input can be valuable for the innovation development of construction companies. In fact, as the requirements related to a building's design and performance increase constantly, it becomes increasingly important for construction companies to actively investigate customer needs, and utilize the feedback in the management, design and development of new services and products (Bock & Linner, 2015). However, clients can also hinder construction innovation for example due to lack of domain experience (Nam & Tatum, 1997).

In addition to clients, systems integrators and manufacturing companies have a central role in construction innovation. In a complex industry such as construction, firms have to rely on the capabilities of other firms to produce innovations (Blayse & Manley, 2004). In particular, the role of a systems integrator, typically principal architect/engineer and/or principal contractor, can be central in construction innovation as an integrator, implementer and even the source of innovation (Slaughter, 1993; Nam & Tatum 1997; Winch, 1998; Slaughter, 2000; Dewick & Miozzo, 2002). In effect, unless the systems integrator is convinced of the merits of the innovation, and has the skills to incorporate it into the system as a whole, innovation implementation is likely to be slow (Nam & Tatum, 1997). The systems integrator's ability to invest in innovation seems to depend on three main factors; the structure of ownership and management, quality of in-house diffusion processes, and collaboration with firms and external sources of knowledge (Dewick & Miozzo, 2002). Finally, the R&D programs of manufacturing companies have been found to be key sources of innovation in the construction sector (Blayse & Manley, 2004).

The implementation of construction innovations in projects is a key phase in construction innovation processes (Winch 1998; Slaughter, 2000; Blayse & Manley, 2004). However, according to the recent literature review on construction innovation presented in Xue et al. (2014), the literature on construction innovation processes at the project level is relatively limited, compared to the literature streams that have gained most attention in construction innovation studies, such as collaboration.

Within the literature focusing on the implementation of construction innovation in projects, a number of studies are based on the research done by

Winch (1998), and Slaughter (1998, 2000). According to Winch (1998), construction innovation has three main processes. First, companies adopt new ideas, second, innovations are implemented in specific construction projects, and third, problem solving and learning during projects brings about new innovations and diffusion capabilities to companies (Winch, 1998). The key point of the model presented by Winch (1998) is that most construction innovations are not implemented in the firm developing the innovation but rather in the construction projects that the firm is engaged in at the time. Therefore, construction companies must first make the decision to adopt innovation, and also be capable of implementing it in projects.

In line with the construction innovation model by Winch (1998), Slaughter (2000) developed a six-stage model for planning the use and implementation of construction innovation in construction projects from the construction company perspective. The aim of the model is to reduce avoidable uncertainty and risk, and increase the effectiveness of innovation use. The six stages of the model are identification; evaluation; commitment; detailed preparation; actual use; and post-use evaluation. The stages are briefly described in the following. At the first stage, construction project objectives and organization are clearly specified. Moreover, potential innovation alternatives to achieve those objectives are searched throughout the value chain and also outside the construction industry.

At the evaluation stage, the preliminary set of innovation alternatives are evaluated in respect to the project objectives and key criteria, e.g., financial targets, building qualities, long-term facility performance and risks (Slaughter, 2000). According to Slaughter (2000) an explicit investigation of the potential benefits of an innovation is necessary at this stage to reveal the full range of the benefits of the innovation to the stakeholders of the project. The aim is to prepare the decision on adopting the innovation. Interestingly, while building investment decisions are typically based on feasibility studies, it seems to be an exception that the potential economic value of construction innovations is evaluated in construction projects. For example, building investment feasibility studies and project documents do not typically contain quantitative analysis of economic life-cycle benefits and costs of design solutions (Elf & Malmqvist, 2009; Zimina et al., 2012). In addition, the adoption of new technologies does not seem to be a systematic process in construction companies. In fact, investment justification is often based on intuition rather than an analysis of benefits and costs (Mitropoulos & Tatum, 1999).

Following the evaluation stage, the construction company commits to the innovation that was selected after the evaluation (Slaughter, 2000). The company's commitment is demonstrated through the allocation of resources to the implementation of the innovation, and often by making a public announcement on its decision to use the innovation. During the preparation stage, the construction project team needs to be able to accomplish two key activities; first to actually obtain the resources; and second to develop and train the personnel who will be involved in the onsite implementation. During the use stage, adjustments and changes are made to the innovation onsite to obtain the expected benefits, or to enhance the level of benefits obtained. Moreover, the on-site personnel learn about the innovation and how to use it. In the final stage, a post-use evaluation is carried out. The evaluation compares the expected benefits and costs to the actual outcomes, and reviews and if necessary updates the project and company evaluation criteria based on the experience with the innovation.

Typically, construction innovations are changes introduced into large, complex systems (Slaughter, 2000). Slaughter (1998, 2000) divides the types of construction innovation into five categories. The categories are incremental, modular, architectural, system, and radical innovation. Incremental innovations are modest improvements in a product, process or system, with no or only minor changes in the links to other components or systems. In contrast, modular innovations have a major improvement in a core concept or area, but no or only minor changes in the links to other areas or components. Architectural innovations assume minor improvements to a core concept or area, but require considerable changes in other components or systems. A system innovation is a combination of innovations that are integrated to provide new functions or attributes. Finally, radical innovation is a significant new concept or approach.

The evaluation and implementation process of construction innovations depends on the type of construction innovation. For example, while the evaluation of an incremental innovation can be straightforward, the evaluation of a system innovation must cover a combination of innovations at the system level. Moreover, a system innovation cannot be directly compared to existing alternatives, since it often provides new features, but may instead be compared to the current existing system in respect to the reaching of the owner's targets (Slaughter, 2000).

2.5 Economic significance of sustainability in the construction sector

The importance of sustainability in the construction sector has been growing during the past decades (Warren-Myers, 2012; European Commission, 2013, World Green Building Council, 2014). Moreover, business opportunities for new cost-effective services and products that improve sustainability in the built environment are substantial (McKinsey & Co., 2009). The application of the concept of sustainable development to the construction and real estate sector has been subject to standardization, for example, in the ISO 15392:2008. The international standard (ISO 15392, 2008) proposes general principles for the analysis of sustainability along the whole lifecycle of buildings. Sustainability is presented as the minimization of adverse impacts and the encouragement of positive spinoffs at both the local and global scale discussing economic, social and environmental aspects. Environmental aspects include the use of resources and impacts on the environment such as energy, water, waste, greenhouse gas emissions and more globally resources depletion, etc. Social aspects encompass impacts on life quality such as health and comfort and interactions with society such as social equity, cultural heritage, etc. Economic aspects include in particular lifecycle costs and the development of property values.

Several earlier studies have found that investing in sustainability and accounting for the value of sustainability has economic significance for construction sector organizations, e.g., property investors (Turner & Frankel, 2008; Fuerst & McAllister, 2008; Eichholtz et al., 2009; Fuerst & McAllister, 2011; Sayce et al., 2013), property developers (Bryson & Lombardi, 2009) and facility management companies (Nousiainen & Junnila, 2008).

Property investors seem to benefit from eco-certified buildings through additional occupier benefits, increased rental income, property value, and decreased property costs. For example, Fuerst and McAllister (2008, 2011) have documented that eco-certified buildings obtain a rental and an asset price premium. The authors found that there is a rental premium of approximately 5% for a LEED (Leadership in Energy and Environmental Design) certification and 4% for an ENERGY STAR certification. Moreover, the premium for sales prices reached 25% for LEED-certified buildings and 26% for ENERGY STAR. In addition, Eichholtz et al. (2009) studied value differences between certified and non-certified properties. They compared properties with ENERGY STAR and LEED certificates to otherwise similar properties.

The results were quite straightforward; the buildings with certificates had approximately 3% higher rents than the buildings without certificates. In addition, studies (e.g., Shiers, 2000; Turner & Frankel, 2008) have shown that operating expenses are lower in certified buildings. However, more research evidence is needed on the connection between sustainability and real estate market value, and practical valuation methods to account for the value of sustainability in order to incorporate the sustainability qualities of buildings in real estate valuation practice (Warren-Myers, 2012).

Sustainability can function as a competitive strategy in property development and facility management. Bryson and Lombardi (2009) found that for property developers the economic benefits of sustainability include enhanced product differentiation, increased ability to attract tenants and investors that have incorporated corporate social responsibility into their business practices, and the reduction of long-term running costs. Moreover, customers expect facility management companies to engage customers into new sustainability business development and value creation. For example, Nousiainen and Junnila (2008) found that large international end-user companies appear to have new kinds of expectations towards facility management companies. Facility management companies are expected to provide services supporting the environmental management of their customers, which offers new business development opportunities for the companies. Moreover, an increasing number of end-user companies wish to receive comprehensive reporting and recommendations on improving the company's or a facility's environmental performance.

In spite of the increasing attention given to the economic impact of sustainability in the construction sector, the academic literature discussing sustainability innovation in the construction sector has emerged only quite recently. Most of the sustainability innovation studies in the sector focus on the role of regulatory authorities (Bröchner et al., 1999; Dewick & Miozzo, 2004; Manley, 2008).

2.6 Summary of the theoretical background

The theoretical background of this research is in innovation research (e.g., Schumpeter, 1942; Schmookler, 1966; Freeman, 1974; Scherer 1982), innovation processes and evaluation of the potential economic value of innovations (e.g., Cooper, 1990; Chesbrough, 2003a; Vargo & Lusch, 2004; Hall, 2004; Greden et al., 2006; Farrukh et al., 2013), construction innovation (e.g., Winch, 1998; Slaughter, 2000) and the economic significance of sustainability in the construction sector (e.g., Fuerst and McAllister, 2008; Eichholtz et al., 2009).

The present study addresses a research gap concerning the evaluation of sustainability innovations in construction company innovation production and construction projects. Previous innovation and construction innovation studies suggest that a company will have an incentive to invest in the development of new services and products only if it can later obtain profits that justify the initial investment. Moreover, earlier literature suggests that innovating together with clients and value networks is essential to develop innovations that are targeted at client needs and to reduce the market and technological uncertainties related to innovation process. However, research and knowledge on how construction companies can evaluate sustainability innovation production is limited. Moreover, earlier construction innovation literature (Winch, 1998; Slaughter, 2000) has identified that construction innovations are implemented in projects and that the evaluation of innovation is a key stage of innovation the implementation process to reduce avoidable uncertainty and risk and increase the effectiveness of innovation use. In particular, the benefits of construction innovations need to be explicitly examined in construction projects. According to earlier studies (Mitropoulos & Tatum, 1999; Slaughter, 2000), more research is needed that addresses the topic both qualitatively and quantitatively in real life construction business and project settings, where investment decisions for innovation need to be made systematically, rapidly and with limited, ambiguous and incomplete data. The research area has also been recognized as a major capacity development area for construction companies and the whole sector (Winch, 1998; Slaughter, 2000). Consequently, there is a need for empirical research on the evaluation of sustainability innovations in the construction sector.

3 Summaries of the papers

This thesis includes six research papers. This chapter presents a summary of the papers. The summaries briefly review the main aims and contributions of each paper from the perspective of their contributions to the research questions of the thesis. Overall, the papers show how construction companies can evaluate sustainability innovations. The full papers are appended to the dissertation.

3.1 Paper I: Global challenges of sustainability business innovations in the built environment

The first paper investigated the challenges of sustainability innovations in the construction sector and the potential solutions to these challenges. In the paper, the challenges of sustainability innovations in the construction sector were evaluated via semi-structured interviews of venture capital investors (VC) and construction companies involved in sustainability innovations. The aim of the analysis was to identify the key challenges facing the construction sector in terms of producing sustainability innovations from the perspectives of construction companies and venture capitalists. The challenges identified in earlier studies were used as background material for the semi-structured interviews. After the analyses, three construction innovation experts were interviewed to evaluate the results and suggest potential solutions to overcome the challenges.

Three VCs and five construction companies were analyzed. The VCs headquartered in Finland have altogether invested more than 480 million euros in sustainability innovations, especially in renewable energies and in energy saving technology companies in Finland and elsewhere in Europe. The companies were specialized in engineering projects, developing and manufacturing steel structures, developing and manufacturing products for indoor environments, developing and manufacturing modular products, and producing lifecycle cost analysis services. Four of the construction companies were based in Finland and one was based in Sweden.

The results of the article imply that *complex value networks* and *team building* are the key challenges of sustainability innovations in the construction sector from the perspective of innovating companies and financiers. Introducing innovations to the market is difficult due to the fragmented nature of the construction sector value network. Consequently, commitment and acceptance by multiple stakeholders is required in the innovation process. Every company and VC also raised the issue of *team building*, as there is a lack of multidisciplinary entrepreneurial teams capable of managing complex value networks and innovations. Moreover, almost all VCs and companies pointed out pending regulatory decisions and the lack of R&D and commercialization management competences as challenges to innovation. Several VCs and companies identified long-term research and development background required for innovation, project-based operations, internationalization, and fundraising as challenges. A summary of the findings is presented in Table 2.

Table 2. Summary of the identified challenges in companies 1-8

Innovation challenge	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Complex value network	X	X	X	X	X	X	X	X
Team building	X	X	X	X	X	X	X	X
Long-term research and development background for innovation	X	X	X					
Pending regulatory decisions	X	X	X	X		X		
R&D and commercialization management				X	X	X	X	X
Project-based operations				X	X	X		
Internationalization						X	X	
Fundraising							X	X

The challenges related to project-based operations in the construction sector, internationalization and fundraising, were present mainly in construction companies. In addition, in contrast to VC investors, all construction companies did not identify pending regulatory decisions as challenges to innovations. Moreover, while VC investors consider the length of time to market and the sunk costs related to sustainability innovations as primary issues in the area of R&D management, the companies felt that it is primarily a question of developing better tools and processes for innovation management.

After the analyses, three construction innovation experts verified that the findings are also applicable in Switzerland and further suggested that they are key challenges more generally related to innovation in Europe. The interviewees argued that client demand is one of main drivers for overcoming the key challenges. In addition, the experts suggested the challenges also include convincing property investors and local policy makers of the benefits of sustainability innovations.

3.2 Paper II: Service-dominant innovation in the built environment

The second paper evaluates how commercial sustainability innovation projects in the construction sector utilize the contemporary market-oriented innovation models based on service-dominant logic (S-D), and the extent to which clients and value networks participate in the innovation projects. The paper analyzes the survey results of 44 company driven sustainability innovation projects in the construction sector. The organizations participating in the innovation projects varied in type and size. In addition to privately owned companies, the participants included public utilities, municipalities and research organizations. There were also differences in the total project budgets, which ranged from under € 50,000 to more than € 10,000,000.

Based on the reviewed literature, a framework for sustainability business innovations (SBI) was created to frame the empirical analysis of the innovation projects. The framework was originally presented in Kajander et al. (2010). The SBI framework consisted of three components: discontinuity of innovation, active client participation and value network involvement. The premise of the framework is that an effective and efficient innovation process is based on customer and value network involvement and ambitious discontinuous innovation targets.

The discontinuity of innovation is one of the components, because instead of incremental steps, businesses should strive to make radical leaps in new products and services. Discontinuity is particularly relevant for sustainability innovation due to the short-time frame available for corrective actions. Discontinuity of innovation entails a twofold benefit of creating new business opportunities, as well as having a potentially greater impact on reducing the environmental burden. Moreover, S-D logic argues that active client participation is beneficial for innovation because it enables companies to target their development efforts according client needs and value. Furthermore, value network involvement enables companies to reduce the need for in-house technological and business expertise, and ensures that external ideas and resources are used in the development project. In addition to these components, a rapid commercialization process with built-in feedback loops is needed for two reasons. First, in regard to the environmental benefits of sustainability innovations, sooner is considered better. Second, entirely new products and services entail great risks. Therefore, development projects aiming at radical innovation should attempt to enter the market at the earliest possible moment. In the framework provided, sustainability is understood as a value that penetrates the entire innovation process, including all of its decision points. A summary of the components involved in the sustainability innovation framework is presented in Table 3.

Table 3. Sustainability business innovation framework (Sivunen et al., 2013)

Primary SBI components	Description
Discontinuity of innovation	Projects should strive to make radical innovations instead of incremental improvements.
Active client participation	The client must be seen as a co-creator of value and thus should participate actively in the entire project.
Value network involvement	The value network consists of actors other than the client, such as regulatory bodies, competitors and universities. Its involvement heightens an organization's sensitivity to external ideas and enables ideas to be exploited more efficiently.

The results indicate that over a third of the examined projects lack all the required innovation components of the SBl framework. Moreover, only 14 percent of projects have all three SBI components in line with S-D logic. Less than half of the projects, 41 percent, include two or three components. The presence of SBI components in the studied projects is presented in Table 4.

Table 4. The frequencies of SBI components in the studied projects (Sivunen et al., 2013)

All three components	13.6% (6)
At least two components	40.9% (18)
At least one component	65.9% (29)
None of the components	34.1% (15)
Note: n = 44	

The active customer participation component refers to the client participating actively in the innovation project, or bearing the main responsibility throughout the entire project. The empirical analysis suggests that active client participation is the most common component in the studied projects with a clear margin for discontinuity of innovation and value network involvement, as displayed in Table 5. The clients participated actively in the projects in over 50 percent of the cases. Clients' active participation in projects, or project responsibility and close cooperation from the idea to the market stage are found in a greater proportion of projects, 70.5 and 61.4 percent, respectively. Furthermore, the few projects that have incorporated the elements of successful SBI in their activities do not seem to utilize feedback from a quick market entry.

Table 5. A comparison of the frequencies at which specific innovation components and subcomponents are present in the examined projects (Sivunen et al., 2013)

SBI component Subcomponent	Percentage frequency (quantity)
Discontinuity of innovation	36.4% (16)
Change in customer behavior	65.9% (29)
Change in organization's value creation	56.8% (25)
Active customer participation	52.3% (23)
Customer is active or bears the main responsibility	70.5% (31)
Close cooperation from the idea to market stage	61.4% (27)
Value network involvement	31.8% (14)
Business-oriented value network	6.8% (3)
Technology-oriented value network	29.5% (13)

Note: n = 44

The paper suggests that sustainability innovations fail commercially in the built environment because they lack active client participation and value network involvement, and they aim for incremental instead of radical improvements. Moreover, the paper demonstrates that S-D logic can be used to understand client and value network involvement in company-driven innovation projects in the construction sector.

3.3 Paper III: Market value of sustainability business innovations in the construction sector

This paper focused on the evaluation of the economic value of SBI to construction sector company shareholders by investigating the possible connection between SBI and firm market value in the construction sector. It continued the research done on SBI in papers I and II by studying whether these innovations have relevance to big construction companies' market capitalization and shareholders. An event study model was used to analyze 30 SBI announcements and the financial information of 10 large international construction companies. The turnover of the companies range from 1.2 billion to 20.2 billion euros, and the companies operate in the fields of construction sector project development, construction related services, engineering and infrastructure, and property solutions, and in several different markets, mostly in Europe.

The research process of this paper had 4 phases. First, previous studies on the effects of environmental performance and innovation on market value, and sustainability innovation in the construction sector were covered to develop a testable hypothesis and select a suitable econometric model. Second, the event study method was presented and the econometric model for this study specified, and following that the abnormal returns were computed and aggregated. The abnormal returns for the event study were computed based on the following methodology (MacKinlay, 1997):

$$AR_{it} = R_{it} - \widehat{\alpha} - \widehat{\beta_i}\mathcal{R}_{mt}$$

where AR_{it} is the period-τ abnormal return for security i; R_{it} is the period-τ normal return for security i; $\mathcal{R}_{mt}$ is the period-τ return on market portfolio m;

$$\widehat{\beta_\iota} = \frac{\sum_{\tau - \tau_0}^{\tau_1} (R_{it} - \hat{\mu}_r)(R_{mt} - \hat{\mu}_{r\tau})}{\sum_{\tau - \tau_0}^{\tau_1} (R_{mt} - \hat{\mu}_m)}$$

$$\widehat{\alpha}_i = \hat{\mu}_i - \widehat{\beta_\iota}\hat{\mu}_m$$

$$\hat{\mu}_i = \frac{1}{L_2} - \sum_{\tau - \tau_0}^{\tau_1} R_{it}$$

$$\hat{\mu}_m = \frac{1}{L_1} - \sum_{\tau - \tau_0}^{\tau_1} R_{m\tau}$$

An appealing quality of the event study method is that the direction of causation is quite clear. In an event study approach, the stock price of the firm is explained by the event after controlling for trends and volatility (Khotari & Warner, 2006). Thus, the event study measures the stock market reaction to new information in an event, which is assumed to be proportional to the net present value of the new information. Third, empirical data was collected and three data sets were constructed; construction sector companies, SBI announcements and financial data. Altogether over 500 potential SBI press releases were scanned and the tentative SBI press releases were analyzed further as to whether they actually contained any SBI components; client involvement, value network integration and discontinuity of innovation. The analysis and classification process for the announcements included four expert group workshops. The workshops focused on a qualitative and quantitative evaluation and ranking of the selected press releases. An announcement was classified as SBI if it was thematically related to sustainability and contained client involvement, discontinuity of innovation and a value network. Finally, the hypothesis on the connection between SBI and firm market capitalization was tested with the event study model for 30 innovation announcements of 10 companies, and the results were presented as shown in Table 6.

Table 6. Results for the base scenario. Table presents the variance $\hat{\sigma}^2_{\tau_1}$ (%), abnormal return AR_t(%), cumulative variance var($\overline{CAR}_\tau$) (%), cumulative abnormal return $\overline{CAR}_\tau$ (%) and cumulative test statistic for the base scenario.

Event date	Company	$\hat{\sigma}^2_{\tau_1}$ (%)	AR_τ (%)	var($\overline{CAR}_\tau$) (%)	$\overline{CAR}_\tau$ (%)	Cumulative test statistic
5 August 2008	Bilfinger	0.093	2.440	0.093	2.440	0.802
7 October 2010	Bouygues	0.017	−0.304	0.027	1.068	0.646
9 November 2009	Bouygues	0.059	1.638	0.019	1.258	0.918
19 August 2010	Costain	0.077	1.674	0.015	1.362	1.099
18 October 2007	HOCHTIEF	0.050	−1.534	0.012	0.783	0.720
9 June 2010	Interserve	0.051	1.435	0.010	0.891	0.909
5 June 2008	Interserve	0.030	0.204	0.008	0.793	0.905
2 July 2009	Leighton	0.192	0.335	0.009	0.736	0.781
19 December 2008	Leighton	0.168	−2.554	0.009	0.370	0.388
16 September 2009	Lend Lease	0.082	3.637	0.008	0.697	0.770
15 June 2009	Lend Lease	0.108	−0.127	0.008	0.622	0.711
22 December 2008	Lend Lease	0.088	0.765	0.007	0.634	0.755
27 August 2008	Lend Lease	0.063	1.103	0.006	0.670	0.839
28 May 2008	Lend Lease	0.038	0.196	0.006	0.636	0.843
17 October 2007	Lend Lease	0.016	0.096	0.005	0.600	0.846
17 July 2007	Lend Lease	0.014	0.111	0.004	0.570	0.852
22 March 2007	Lend Lease	0.013	1.942	0.004	0.650	1.027
11 March 2010	NCC	0.037	0.972	0.004	0.668	1.100
5 February 2009	NCC	0.073	1.028	0.004	0.687	1.159
2 December 2010	Skanska	0.009	1.381	0.003	0.722	1.277
25 November 2009	Skanska	0.009	0.584	0.003	0.715	1.324
10 February 2009	Skanska	0.062	−0.232	0.003	0.672	1.274
28 September 2010	YIT	0.038	−0.347	0.003	0.628	1.227
26 March 2010	YIT	0.059	1.037	0.003	0.645	1.288
2 February 2010	YIT	0.075	−0.421	0.002	0.602	1.222
29 October 2009	YIT	0.107	2.829	0.002	0.688	1.403
7 October 2009	YIT	0.112	−2.531	0.002	0.569	1.165
6 October 2009	YIT	0.112	3.768	0.002	0.683	1.406
26 January 2009	YIT	0.134	3.760	0.002	0.789	1.624
3 October 2008	YIT	0.107	1.739	0.002	0.821	1.703

As illustrated in Table 6 there are a total of 30 SBI announcements of which 22 have positive abnormal return AR_t(%) and 8 have negative abnormal return. The cumulative abnormal return $\overline{CAR}_\tau$ (%) for all events is 0.82%, which is statistically significant at the 0.05 significance level. The results imply that shareholders seem to recognize the potential economic value of SBI in construction companies. The empirical findings indicate that SBI announcements and firm market value in the construction sector are statistically significantly and positively associated. SBI announcements are associated with a 0.82% increase of a construction firm's stock market returns. The main finding is well-aligned with the findings from earlier studies suggesting that innovation announcements (e.g., Chaney et al., 1991) and sustainability announcements (e.g., Klassen & McLaughlin, 1996) are positively associated with abnormal stock price increases.

The findings are relevant for the top management of construction companies in terms of business development. In effect, public commitment to SBI may have a positive shorter-term impact on construction company market capitalization. Information on SBI can be useful to stock market investors for assessing the future growth potential of a construction firm. It could be that an SBI announcement can be seen as a proxy for a firm's innovation capability and a subcomponent of a firm's intangible assets that generate future cash flows.

3.4 Paper IV: Valuing flexibility in a retrofit investment

This paper studied how real option analysis (ROA) can be used to evaluate a sustainability innovation investment that enhances building physical flexibility in a construction project. The purpose of this paper was to explore how ROA can be used for valuing flexibility in an office retrofit project, present a research process for valuing the flexibility in the retrofit investment case, and evaluate the empirical usability of real option valuation results compared with traditional discounted cash flow (DCF) valuation results. This paper acknowledges that ROA has been developed particularly to emphasize the uncertainty of future cash flows. In contrast to the current industry standard for investment evaluation, the discounted cash-flow method, it operates with future options rather than adjusting financial variables such as the discount rate, which could result in myopic decisions particularly when evaluating new service and product concepts.

In this paper, the potential economic value of flexibility was evaluated in a case study, which is an office retrofit project of a large property owner in Finland, Senate Properties. Senate has experienced that DCF cannot properly independently address the uncertainty in the space requirement of the tenants. In short, the uncertainty is incorporated into the DCF by adjusting the discount rate, which is a single number depiction of the risk of an investment. Thus, for determining the economically justifiable value of flexibility, Senate would have to determine the difference in the discount rate between a flexible building and a non-flexible building. Compressing the uncertainty of the space requirements into a single percentage number is not very intuitive and comprehensible. On the other hand, in ROA, the range of uncertainty is examined without adjusting the discount rate.

A newly introduced ROA method, the fuzzy pay-off method (FPOM) for real options valuation (Collan et al., 2009), was used for valuing the flexibility. The main advantage of the method is its practical applicability, i.e., only three scenarios (minimum, best guess and maximum) are needed for the valuation. These three scenarios are treated as triangular fuzzy numbers that form a triangular pay-off distribution where the best guess scenario has complete membership, the minimum and maximum scenarios have complete non-membership, and the other scenarios in-between have intermediate degrees of membership. This asymmetrical information is used as the basis to form a triangular pay-off distribution that is “a graphical presentation of the range of possible future pay-offs the investment can take” (Collan et al., 2009), which is illustrated in Figure 2.

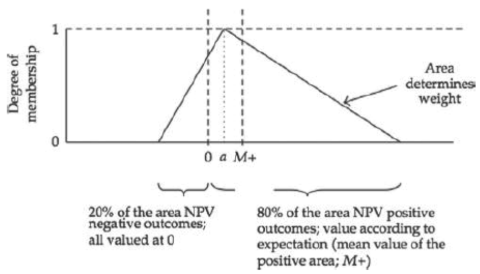

Figure 2. A triangular pay-off distribution defined by three points describing the net present value of a prospective investment; percentages 20 and 80 are for illustration purposes only.

A seven-phase research process was used to create the three scenarios required for the FPOM. The research process involved defining vacancy scenarios for rental agreements, transforming them into potential income achievable with flexibility, estimating the cost of flexibility, comparing the potential income with the costs and valuing the real options. The data of this paper included investment case, rent-roll, building design and layout data and data from expert workshops.

The case study shows that a specific type of innovation investment that enhances sustainability, physical flexibility, can be evaluated with ROA from the client and tenant perspective. In particular, the applicability of the fuzzy pay-off method into a practical investment case was found straightforward, because the assignment of probabilities into different uncertainty scenarios was unnecessary. For the case building, the present value of the pay-off from flexibility ranged from negative 58 eur/sqm to positive 130 eur/sqm, depending on the tenant.

The analyses revealed the economically feasible extent of flexible space and where it should be located. For the client, the Senate, these analyses provided guidelines for the designers to plan the new layout to be as economically optimal as possible. The tenant specific analyses are an important addition to the first argument that the whole building should not be constructed to be flexible.

This paper points out that the client's investment experts perceived ROA as a valuable approach to systematically sharing and analyzing investment decision-making information inside the company. The main advantage of the method compared to DCF valuation was the handling of uncertainty, i.e., individual tenant risks were assessed more carefully and systematically by acknowledging several sources of information. Also, the projection of the three scenarios into the building layout provided Senate with a comprehensible result that showed the potential vacancy for each. tenant.

3.5 Paper V: Valuing indoor air quality benefits in a healthcare construction project with real option analysis

The fifth paper investigated and demonstrated ROA as a new approach to the evaluation of the economic benefits and pay-off of sustainability innovation in a real life construction project. The research was carried out as a case study, which was a healthcare construction project in Finland aiming to produce new facilities for over 280 healthcare professionals. The evaluated sustainability innovation investment in the case study was a modifiable ventilation system. The system enables adding more ventilation capacity and increasing ventilation rate if necessary, which can produce significant economic benefits to the tenant during the use of the building. The economic benefits of a modifiable ventilation system were measured as cost savings from a potentially lower sick leave rate for the tenant organization. In this study, the fuzzy pay-off method (FPOM) was used to compute real option values. Moreover, the main sources of data consisted of tenant's strategic plans, case projects' feasibility study reports, articles and briefing, and expert workshops.

The research process, i.e., the valuation of the potential economic benefits of the modifiable ventilation system investment, proceeded in seven steps:

1) Documenting the current state of the tenants' personnel sick leave rate and annual costs and estimating yearly personnel reduction/growth (i.e., the

percentage of personnel per year) and the distribution of the sick leave rate during the investment period;

2) Assessing the potential effect of increased ventilation rates on the sick leave rate based on the findings from earlier literature and expert workshop;

3) Comprising three different scenarios of annual sick leave rate reductions by connecting the findings from phases 1 and 2;

4) Converting the scenarios into potential cost savings scenarios achievable with increased ventilation rates;

5) Calculating the real option value of the economic benefits using the potential cost saving scenarios;

6) Calculating the costs of investments;

7) Calculating investment pay-off, i.e., real option pay-off for the investment by converting the cost savings scenarios to net pay-off scenarios by taking into account the costs of investments.

The main finding of this article is that ROA seems to be a viable method to evaluate the economic benefits and profitability of investments in sustainability innovation, such as a modifiable ventilation system, in real life construction projects. The investments seem to have several option characteristics such as high uncertainty and long investment period. ROA with FPOM takes this uncertainty of into account through three pay-off scenarios: minimum, best guess and maximum. This is also a key difference between ROA and DCF investment calculations as DCF typically accounts only for one pay-off scenario and the discount rate is adjusted to account for uncertainty, which is not very intuitive and comprehensible.

While the results of this study are only suggestive, the economic benefits associated with better indoor air quality (IAQ) seem to be considerable. The economic benefits of better IAQ was almost 4 million euros and the modifiable ventilation system investment had a positive real option pay-off exceeding 0.5 million euros. It appears that for the tenant it is profitable to pay up to 5.3% (1.6 eur/SQM/month) higher rent for the building with a modifiable ventilation system compared to a similar building in the same location with only a standard ventilation system, keeping other things equal.

The results from this quantitative analysis revealed interesting insights also to the investor. In effect, in the case that the tenant is willing to pay such a premium for better IAQ through a modifiable ventilation system in the new building, better IAQ can also be seen as a rental upside for the building owner. The magnitude of the economic benefits of IAQ investments documented in this article is in line with findings from earlier studies (e.g., Fuerst and McAllister, 2008; Eicholtz, 2009) on the increased rental income of eco-certified buildings.

The managerial construction of this analysis, i.e., the ROA process and output presented in this study, was used as an investment feasibility analysis document in the actual investment decision-making process of the project. The decision-makers appreciated particularly the systematic ROA process which brings experts together to incorporate the sources of uncertainty and the numerical presentation of the potential economic benefits and costs related to the investments. Later on in the building briefing process, the results of this analysis were applied in setting the target value of design for the ventilation system. Moreover, the ROA approach was also used for the optimization of building service flexibility and adaptability in the project.

The results have practical implications for investors, designers and tenants. ROA is a promising approach to analyze the potential economic value of sustainability innovation investments. Moreover, ROA may help to alleviate the potential principal-agent and asymmetric information problems in the investments. In practice, it may facilitate project stakeholders to effectively and transparently communicate the characteristics, uncertainties and benefits of the investments. The empirical analysis produced in this paper was perceived valuable by the case study tenant and investor and can be used as guidance and motivation for further applications of analyzing the economic benefits of and setting targets for indoor environment investments.

3.6 Paper VI: Risk management with real options in public private partnerships

The sixth paper addresses the evaluation of sustainability innovation investments in a real life Public Private Partnerships (PPP) construction project setting. PPPs are an established alternative to direct investment in construction projects in the municipal sector. The purpose of this paper was to use ROA for evaluating risk management actions and investments in a healthcare project based in Finland. The three main sources of uncertainty were identified related to the targets of the client organization of the project. Accordingly, the risk management investments for managing the uncertainties were proposed and their potential economic value was examined with the developed ROA process. ROA was used to evaluate investments in flexible design, physical flexibility of the healthcare building and a building integrated on-site source energy.

The potential economic value of flexibility designed in a parking structure was 680 000 € in comparison to the original design. Physical flexibility for managing the uncertainty in final space demand was found to have a value of 460 000 €. The building integrated on-site energy source production for addressing the uncertainty in raising energy costs was found to have an option value of 440 000 €. The client received benefits from ROA such as decision-making information directly applicable to investment decision and guidelines for developing briefing and design management documents; thus, potentially improving project profitability in later life-cycle stages.

This case study showed that ROA can be used to evaluate opportunities and uncertainties inside a PPP project, and to evaluate the potential economic value of investments to realize opportunities and cope with the uncertainties.

4 Conclusions and discussion

4.1 Summary of the results

The aim of this research is to examine the evaluation of sustainability innovations in the construction sector as well as demonstrate the use of real option analysis for the evaluation of the potential monetary benefits of sustainability innovation investments. Next, the findings of the papers are discussed relative to the aim of the research.

The results of the qualitative and quantitative data suggest that construction companies can evaluate their sustainability innovation development by investigating client and value network engagement in their innovation projects. The results of the present study imply that the complex value network of the construction sector is a key challenge of sustainability innovations as commitment and acceptance by multiple stakeholders is required in the innovation process to introduce sustainability innovation to the market (Paper I) and that this challenge could be alleviated through client demand and integration (Paper I). This is in line with S-D logic (Vargo & Lusch, 2004), which argues that the value of an innovation is co-created together with the customer and the value network during the innovation process. Based on the fundamentals of S-D logic, an SBI framework was created in this research to evaluate the client and value network engagement in company driven sustainability innovation projects (Paper II). The framework consisted of three components; active client participation; value network involvement; and discontinuity of innovation. The premise of the framework is that an effective and efficient sustainability innovation process is based on customer and value network involvement and ambitious discontinuous innovation targets. According to the empirical results, a considerable share of the projects are carried out and economic value is created without active participation of clients and value networks. In fact, half of the studied projects lacked active participation by the client, over 65% of the projects had not integrated the value network, and utilization of market feedback for rapid market entry was infrequent (Paper II). The findings suggest that the understanding of the client and value network involvement in a company's sustainability innovation projects is central to construction companies, and S-D logic can be used to improve that understanding (Paper II).

In order to understand whether sustainability innovations in the construction sector already have actual shareholder value, an event study was constructed to analyze the shareholder value relevance of sustainability innovation production (Paper III). In an event study approach, the stock price of the firm is explained by the event, in this case SBI announcement, after controlling for trends and volatility (Khotari & Warner, 2006). The results imply that stock market investors recognize and positively value the SBI announcements of construction companies (Paper III). The announcements and firm market value in the construction sector are statistically significantly and positively associated; an announcement is associated with a 0.82% increase of a construction firm's stock market returns. The main finding is well-aligned with the findings from earlier studies suggesting that innovation announcements (e.g., Chaney et al., 1991) and sustainability announcements (e.g., Klassen & McLaughlin, 1996) are positively associated with abnormal stock price increases. It could be that SBI announcement can be seen as a proxy for a firm's innovation capability and a subcomponent of a firm's intangible assets that generate future cash flows. In particular, the client and value network engagement described in the announcement may signal to investors that a construction company's innovation process is managed well relative to identified challenges of sustainability innovations (Paper I).

Earlier studies (Winch, 1998; Mitropoulus & Tatum, 1999; Slaughter, 2000) have suggested that the evaluation of the potential benefits of an innovation in a construction project is a key stage of the construction innovation process. In particular, the evaluation of the potential benefits appears to be essential for sustainability innovations in the construction sector to overcome a key challenge concerning convincing property investors and local policy makers of the benefits of sustainability innovations (Paper I).

In practice, this evaluation of the potential benefits can be a challenging task, which is carried out in a limited timeframe and with incomplete data. The findings suggest that real option analysis (ROA), particularly the fuzzy pay-off method (FPOM), can be used to evaluate the potential monetary benefits of sustainability innovation investments in the feasibility evaluation phase of construction projects (Papers IV, V and VI). ROA processes for the evaluation of potential monetary benefits were proposed, and FPOM for ROA was used to evaluate the potential monetary benefits of physical flexibility, modifiable ventilation system, a building integrated energy production system and the flexible design of a car-parking garage to clients and tenants in real life construction projects (Papers IV, V and VI). The case studies suggest that sustainability innovation investments seem to have several option characteristics such as high uncertainty and a long investment period. As demonstrated by the findings (Papers IV, V and VI), FPOM takes this uncertainty into account by systematically setting three pay-off scenarios; minimum, best guess and maximum. This is also a key difference between ROA and traditional DCF investment calculations as DCF typically accounts only for one pay-off scenario and the discount rate is adjusted to account for uncertainty. The analyses presented in Papers IV-VI demonstrate that FPOM can be applied in real life project decision-making situations with limited timeframe and incomplete data (Papers IV, V and VI). Furthermore, the feedback from practitioners in Papers IV-VI suggests that the proposed ROA process can enhance investment decision-making for example by bringing project stakeholders together to share investment decision-making information, identify the sources of uncertainty and review the numerical presentation of the economic benefits and costs of sustainability innovation investments.

Together the findings provide a fresh view on the evaluation of sustainability innovations in the construction sector, both at construction company and project levels. The findings add to the knowledge on the evaluation of sustainability innovations in the construction sector by examining and demonstrating new systematic approaches, i.e., event study and ROA for the evaluation of sustainability innovations in the construction business and project contexts. Figure 3 illustrates the key findings of this dissertation.

Overall, this dissertation provided answers to both research questions and found that construction companies can evaluate sustainability innovations by investigating the potential monetary benefits of sustainability innovations (RQ1). Construction companies can evaluate their sustainability innovation production by investigating and understanding the client and value network engagement, and examining the shareholder value relevance of their sustainability innovation projects (RQ1). In addition, in construction projects construction companies can evaluate sustainability innovation investments by examining the potential monetary benefits to clients and tenants with ROA (RQ2). This dissertation makes the following proposals:

i. Construction companies should evaluate sustainability innovations together with clients and the value network to systematically manage the development and adoption of sustainability innovation in the construction sector; and

ii. Construction companies can evaluate the potential monetary benefits of sustainability innovation to shareholders with event study and to clients and tenants with real option analysis.

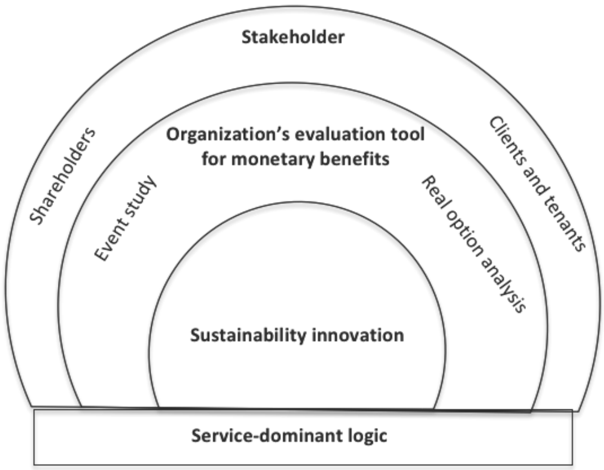

Figure 3. The structure of evaluating sustainability innovations in the construction sector in the dissertation

4.2 Contribution of the research

This research contributes to the body of knowledge on managing sustainability innovations in the construction sector and demonstrates managerial tools for the evaluation of sustainability innovations in the construction sector. The contribution of this dissertation can be assessed by first looking at the parts individually and then in their entirety.

The presented theoretical background introduces and organizes relatively scattered literature on the evaluation of sustainability innovations in the construction sector. The theoretical background is useful for both researchers and practitioners, because it introduces the state of the art of research and managerial implications.

Paper I empirically analyzed sustainability innovation challenges at the construction company level. The paper was the final publication in a unique series of papers (Kajander et al., 2010; Kajander et al., 2011; Sivunen et al., 2011) investigating the topic and it increases our understanding of the current challenges of sustainability innovation in the construction sector. The main findings of the paper were in line with earlier construction innovation studies and underlined complex value networks as the key challenge for sustainability innovation in the construction sector, and the importance of client demand for overcoming the key challenge. Furthermore, the paper suggested that the challenges also include convincing property investors and local policy makers of the benefits of sustainability innovation.

Paper II examined customer and value network engagement of sustainability innovation projects in the construction sector. The paper is among the first studies to test S-D logic in the context of the construction sector and empirically evaluate client and value network engagement in sustainability innovation projects in construction.

Paper III was the first known study to test statistically the connection between sustainability innovations and the market value of construction companies. The paper makes an empirical contribution by investigating the shareholder value relevance of sustainability innovation.

Paper IV showed how investments in physical flexibility can be evaluated with ROA from the real estate owner and tenant perspective. The paper makes an empirical contribution by demonstrating the use of ROA in a real life construction project. Real options literature, especially in the real estate and construction sector, has been calling for new applications of ROA in a practical setting. This paper adds to it with an example of evaluating flexibility in a retrofit investment case.

Paper V was among the first studies to apply ROA to analyze the potential monetary benefits of indoor air quality (IAQ) to the building owner and tenant in a real life construction project. The empirical contribution of the paper is in the evaluation of a modifiable ventilation system investment with ROA in a real life construction project. By examining the economic benefits of the investment, this study increases understanding of how the potential monetary benefits of sustainability innovation investments can be evaluated at the feasibility evaluation phase of construction projects.

Paper VI showed that ROA can be used to reveal opportunities and uncertainties inside a PPP project, and the paper deepens our understanding on how to evaluate the potential economic value of innovative investments to realize opportunities and cope with uncertainties.

Overall, the dissertation contributes to the literature of construction innovation by examining empirically the evaluation of sustainability innovation in the construction sector. It does so by investigating and suggesting a systematic approach to evaluate sustainability innovation in construction business and project decision-making from the construction company perspective. In particular, the approaches help construction company practitioners to evaluate the potential monetary benefits of innovations to shareholders, clients and tenants.

This dissertation indicates that sustainability innovations need to be carefully evaluated by construction companies as client and value network engagement seems to be central for creating successful sustainability innovations in the sector, and stock market investors have recognized their role, and investments in sustainability innovation can be unprofitable. Practitioners can use service-dominant logic to understand the client and value network engagement of sustainability innovation production, and event study to evaluate the shareholder value of sustainability innovations.

In particular, this research is motivated by and continues the work of Slaughter (2000) on systematic approaches to evaluate innovations in real life decision-making situations in the construction sector. The aim of Slaughter's (2000) work is to reduce avoidable uncertainty and risk, and increase the effectiveness of innovation use. The present study continues the work of Slaughter (2000) by investigating and suggesting methods for the evaluation stage of the innovation process. In practice, ROA is a potential approach for the evaluation of sustainability innovation investments in respect to project objectives. ROA facilitates the explicit investigation of the potential benefits of innovation, which is necessary to reveal the full range of benefits to the stakeholders of the project. In particular, FPOM would seem to work well in real life project decision-making situations with a limited timeframe and incomplete data to quickly evaluate the feasibility of promising sustainability innovation investment alternatives. In effect, ROA is a promising tool for construction innovation gatekeepers to conduct investment feasibility studies that contain quantitative analysis of life-cycle economic benefits and costs of design solutions that for example Elf & Malmqvist, (2009) and Zimina et al. (2012) call for. Moreover, ROA can help practitioners to reduce avoidable uncertainty and risk of innovation implementation, and increase the effectiveness of innovation use.

4.3 Evaluation of the research

This section evaluates the mixed-method research process and the quality of the research. A mixed-method study can be evaluated using the following criteria (Creswell & Plano Clark, 2011; Creswell, 2014):

- use of a mixed methods design;
- employment of rigorous procedures in the methods used for data collection and analysis;
- collection of both quantitative and qualitative data and analyzing them;
- merging, embedding or connecting the databases so that their combined use provides a better understanding of the research problem than just one source or the other;
- use of consistent mixed methods terms

The present study uses convergent design and integrates all features of the design, as presented by Creswell and Plano Clark (2011). In this study, both quantitative and qualitative data have been collected and analyzed using rigorous procedures, as presented in each paper. Furthermore, the research connected the data sources and findings to provide a more comprehensive understanding of the research problem. For example, qualitative case study data was utilized to develop and demonstrate ROA for evaluating the potential monetary benefits of sustainability innovation investments. This would not have been possible by utilizing only quantitative data. In contrast, the quantitative data revealed new insights on the engagement of clients and the value network in construction innovation processes that would not have been possible to generate utilizing only qualitative data. Finally, this dissertation uses research terminology according to Creswell (2014).

The quality of any empirical social research is typically evaluated using four tests of construct validity, internal validity, external validity and reliability (Yin, 2014), which are discussed in the following. Construct validity refers to identifying correct operational measures for the concepts being studied (Yin, 2014). Construct validity can be improved by using multiple sources of evidence, establishing a chain of evidence and having key informants review the drafts of study reports. In the present study, the construct validity was improved by collecting multiple data sets, and analyzing the data sets with qualitative and quantitative methods. Moreover, each paper presents a chain of evidence. Finally, the findings of this research have been benchmarked against earlier research and to a large extent reviewed by informants.

Internal validity is a concern for explanatory research, when an investigator is seeking to establish causal relationship (Yin, 2014) as in the case of event study research. In this research, internal validity was carefully enhanced through the following procedure. First, an initial theoretical statement or explanatory proposition was formulated. After that, the findings were compared to the statement and the statement was revised. Finally, the revised statement was compared against the other details of the case, and in the case studies examining ROA to the findings from the other cases. This procedure was a series of iterations to increase internal validity (Yin, 2014).

External validity refers to the generalizability of results beyond the scope of the immediate study (Yin, 2014). This mixed-method study utilizes both qualitative and quantitative data. Consequently, the generalizability of the results is better than in the case of using only one type of data (Cresswell, 2014). However, the empirical analysis of the present study is limited in terms of innovation orientation and geographical area. The main target groups of this research were innovative construction companies and clients in Finland. Consequently, the generalizability of the results to the whole construction sector is limited as only a limited number of construction companies are innovation-oriented. Moreover, the results of this dissertation are to some extent generalizable to innovation-oriented construction companies outside Finland. While the majority of the data was collected in Finland, the data contains characteristics that indicate that the results are generalizable to other countries. For example, Paper I contains interviews and validation data of international experts collected in Switzerland, and the event study in Paper III contains data from Germany, the United Kingdom and Australia. Moreover, the findings were continuously compared to earlier international literature and expert feedback. In addition, the evaluation methods examined in the present study have been applied in other contexts in earlier literature, for example, in finance and managerial systems.

The key idea of the reliability test is that a researcher who follows the same procedures and conducts the same study over again as the earlier researcher, arrives at the same results and conclusions (Yin, 2014). The aim of reliability is to minimize the errors and biases in a study. Yin (2014) proposes the means of using a study protocol and developing a study database to improve the reliability of research. The present study was carefully planned in advance including research data collection procedures and questions, and reporting of results. In addition, the research progress and results were monitored and reviewed regularly by the co-authors of the papers. Documentation and the archiving of data and evidence were taken care of and the data was securely stored. Furthermore, a study database was developed, and all data, including transcribed interviews, company and project data and questionnaires, have been stored. Finally, the results of this research have been reviewed by several external experts during the academic peer-review and publishing process as well as reported publicly internationally.

4.4 Future research

This study has been an empirical investigation on the evaluation of sustainability innovations in the construction sector. The results of this research offer a basis for three principal future research directions.

First, further research is needed to validate and enhance ROA and event study for the evaluation of the potential monetary benefits of sustainability innovation. It would be valuable to study ROA in different empirical settings and also conduct follow up studies to provide more evidence on whether the assumptions and results of ROA case studies are valid and reliable when the case buildings become operational. Moreover, future researchers could repeat the event study of this dissertation with a larger data set as an increasing number of construction company sustainability innovation announcements are available.

Second, the results and research experiences of this dissertation suggest that besides the evaluation of sustainability innovation investments ROA has also potential for building design target setting especially in the complex construction projects of owner-occupier organizations. ROA could be used to set targets for construction projects' monetary benefits, costs, building design and qualities, and schedule. In essence, it could be that ROA target setting enables a better common understanding of potential monetary benefits related building qualities for project stakeholders. A benefit-driven construction project management model could improve the incentives for innovation through value-based gain-sharing approaches, and facilitate the adoption of sustainability innovations in projects. Therefore, future research should consider ROA as a tool to set targets for construction projects.

Finally, a key avenue for further research and for the construction sector is taking the Slaughter model (2000) for construction innovation implementation further by establishing a practical innovation evaluation theory for construction decision-makers based on scientific evidence and case examples. The theory should address continuous innovation scanning and evaluation, and the engagement of clients and the value network to construction innovation projects. Hopefully the new knowledge created in this research on the evaluation of sustainability innovations in the construction sector acts as an impetus for the future research for this theory.

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Climate change mitigation market offers huge business opportunities for new construction services and products that improve sustainability in the built environment. The aim of this research is to examine the evaluation of sustainability innovations in the construction sector as well as demonstrate managerial practises for the evaluation of sustainability innovations for construction companies. This dissertation finds that construction companies can evaluate sustainability innovations by investigating the potential monetary benefits of sustainability innovations and it makes the following proposals: (i) Construction companies should evaluate sustainability innovations together with clients and value network to systematically manage the development and adoption of sustainability innovation; and (ii) construction companies can evaluate the monetary benefits of sustainability innovation to shareholders with the event study method, and to clients and tenants with real option analysis.

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