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Value creation and capture in systemic innovation implementation: case of mechanical, electrical and plumbing prefabrication in the Finnish construction sector

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Abstract

Purpose – Systemic innovations emerge and create value in an inter-organisational context. However, innovation studies rarely investigate the role of value creation and value capture among multiple organisations in successful innovation implementation. This paper aims to understand the role of value creation and value capture in the implementation of systemic innovations in construction which is by nature, an inter-organisational context.

Design/methodology/approach – The empirical research focused on the barriers, enablers and opportunities for value creation and value capture of the Finnish construction project parties when trying to implement mechanical, electrical and plumbing (MEP) prefabrication, which is a systemic innovation. Data were collected through interviews, observations and action workshops.

Findings – The empirical study identified interaction patterns on how social, political, technical and economic barriers lead to uneven value capturing, lack of value-based procurement and unclear value creation between MEP design and installation. They hinder the implementation of MEP prefabrication. The results point to enablers leading to fairly shared value to all parties, procurement of value and collaborative value creation, thus increasing the usage of MEP prefabrication, a systemic innovation.

The research was conducted as part of the Aalto University's research project "Building 2030 - industrialized construction" which is funded by 19 companies operating in the real estate and construction sector. The Finnish Science Foundation for Economics and Technology has also financed the research. Earlier results have been published in a conference paper by Lavikka, R., Chauhan, K., Peltokorpi, A. and Seppänen, O. (2018) Fostering prefabrication in construction projects - case MEP in Finland in eWork and eBusiness in Architecture, Engineering and Construction, eds. Karlshoj, J. and Scherer, R. Taylor and Francis Group, London, UK. Proceedings of the 12th European Conference on Product and Process Modelling (ECPPM 2018), Copenhagen, Denmark, 12-14 September 2018.

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Originality/value – The study adds new knowledge by demonstrating that the identification of barriers and their interaction with enablers and opportunities for value creation and capture lay a baseline for suggestions on how to implement a systemic innovation. This study stresses the importance of enabling value creation and capture for all construction project parties when implementing a systemic innovation.

Keywords Construction, Value creation, Value capture, Systemic innovation, MEP, Prefabrication

Paper type Research paper

Introduction

Construction innovations can be categorised either as *autonomous* or *systemic* depending on their effects on the construction supply chain and its parties. An autonomous innovation can be implemented by a single organisation and does not modify the other components of the supply chain. In contrast, a systemic innovation necessitates changes by multiple parties in a single process and are therefore difficult to implement in project networks, which are fragmented and consist of numerous parties (Gann and Salter, 2000; Blayse and Manley, 2004; Taylor and Levitt, 2004; Katila *et al.*, 2018). Most research on innovation implementation in construction has emphasised autonomous innovations that usually change existing processes inside one company. This study focuses on the implementation of systemic innovations that are often misaligned with the structures of the construction project network (Hartmann, 2006).

Previous studies have focused on understanding how integrative practices increase the adoption of systemic innovations (Hall *et al.*, 2018, 2020), the effects of systemic innovations in one organisation (Lindgren and Emmitt, 2017) and the structural mechanisms that impact the diffusion of systemic innovations (Taylor and Levitt, 2004; Alin *et al.*, 2013). Although these studies on systemic innovation in construction exist (Alin *et al.*, 2013; Lindgren and Emmitt, 2017; Hall *et al.*, 2018), little is known about the connection between value creation, value capture and the success of systemic innovation implementations in the context of construction. Interestingly, innovation studies, in general, rarely seem to investigate the connection between value creation and inter-organisational relationships, even though value creation is facilitated when inputs from the parties are complementary, or task coordination between the parties exists (Pulkka *et al.*, 2016). Also, studies on construction innovation implementation call for research that considers the role of inter-organisational interaction in construction supply chains (Gambatese and Hallowell, 2011; Bygballe *et al.*, 2015; Hall *et al.*, 2018). This study addresses these research gaps by analysing the potential value creation and capture of construction project parties in the context of implementing a systemic innovation in construction. The study poses the following research question. What is the role of value creation and value capture when implementing a systemic innovation in construction? The study is positioned in the body of research on systemic innovation implementation in project-based construction.

The empirical research focuses on analysing the opportunities for value creation and capture of project parties when aiming to implement mechanical, electrical and plumbing (MEP) prefabrication. MEP prefabrication fulfils the characteristics of a systemic innovation because the use of prefabricated products changes the current roles of construction parties. MEP design and construction involves a high degree of interaction between architectural, structural, mechanical, electrical, fire protection and plumbing work of different companies. According to Chesbrough and Teece (1996), innovation is systemic if its benefits can be realised only in conjunction with complementary changes in other parts of the system, and members of the system are dependent on the other members over whom they do not have control.

Construction projects are predicted to benefit significantly from prefabrication (Wuni and Shen, 2019). For example, a study showed that when all the plumbing and low-pressure ductwork were prefabricated, the general contractor could maintain a safe and efficient construction site, and MEP work productivity improved between 5 and 25% through efficient work coordination using building information modelling (BIM) (Khanzode *et al.*, 2008). Finland has a long history in the prefabrication of steel and concrete elements. However, the country has not been able to implement the prefabrication of MEP building systems on a broader scale. Curiously, MEP prefabrication has been commonplace for decades in some other countries, such as the USA, Australia, the UK and China. Studies show that traditional construction business in these countries is continuing to adopt MEP prefabrication (Khanzode *et al.*, 2008; Bekdik *et al.*, 2016; Hanna *et al.*, 2017). As MEP prefabrication is rarely applied in the Finnish construction projects, they provided a fruitful empirical research context.

The findings highlight how the current contextual setting of the Finnish construction projects hinders the implementation of a systemic innovation. The discussion focuses on demonstrating that the identification of barriers and their interaction patterns with enablers and the opportunities for value creation and capture lay a baseline for implementing a systemic innovation. The contribution of this study lies in adding new knowledge about the connection between value creation and capture and systemic innovation implementation in the inter-organisational construction context.

Implementing systemic innovations in construction

According to Hartmann (2006), construction innovation is any new idea that is successfully implemented into an inter-organisational construction project. Construction innovations are often driven by the clients' demand for new types of buildings with new structures as well as by modern methods of construction and manufacturing (Gann and Salter, 2000). Case studies on construction projects in the USA have shown that the general components of innovation are idea generation, opportunity and diffusion (Gambatese and Hallowell, 2011). Each innovation component requires support and commitment from the client and project management, the integration of the workforce and project team as well as diversity (Gambatese and Hallowell, 2011). Rogers (2003, p. 11) describes innovation implementation as "the process by which an innovation is communicated through certain channels over time and among the members of a social system".

Barriers and enablers for implementing systemic innovations in construction

Over 30 years ago, Tatum *et al.* (1987) showed that prefabrication, pre-assembly, modularisation and offsite fabrication (PPMOF) could increase construction project performance. More recent studies have also demonstrated that PPMOF can lead to project productivity and quality improvement (Pan *et al.*, 2008), completion of projects on budget and on time, reduced construction costs (Pan and Sidwell, 2011), minimisation of waste by 52% (Jaillon *et al.*, 2009), reduced health and safety risks (Pan *et al.*, 2012) and improved environmental performance of building construction (Mao *et al.*, 2015). Construction companies adopt PPMOF for numerous reasons, such as shortened construction duration, reduced construction and labour costs as well as enhanced quality (Wong *et al.*, 2017). In addition to these reasons, a literature study revealed that companies also prefer PPMOF, when aiming not only for better productivity and improved competitiveness but also for sustainability and policy reasons (Wuni and Shen, 2019). As a result, the use of PPMOF, specifically modularisation and offsite fabrication, has been increasing worldwide (Li *et al.*, 2017; Wuni and Shen, 2019).

Despite the advantages of applying PPMOF, its implementation has been slow due to social, political, technical and economic barriers. A risk-averse culture is one of the social barriers (Pan *et al.*, 2008). Risks are avoided due to the uncertainty that stems from the multiple project environment, short-term buyer–supplier relationships, lack of trust between contractors and suppliers and the reluctance of suppliers to adopt new standards (Pan *et al.*, 2012; Mao *et al.*, 2015; Bekdik *et al.*, 2016). Also, the lack of multi-skilled labour is a social barrier to offsite construction (Zhai *et al.*, 2014). Often labour is specialised in specific tasks, whereas factories demand that workers be skilled in many construction tasks (Goodier and Gibb, 2007; Hamzeh *et al.*, 2017).

The political barriers stem from several sources, such as the absence of government regulations and incentives (Mao *et al.*, 2015), overly complicated and time-consuming regulative procedures (Halman *et al.*, 2008) or the lack of incentives for prefabrication (Pan *et al.*, 2012). Rigid labour union rules also restrict prefabrication (Said, 2015).

Technical barriers originate from complex interfaces between subsystems and the lack of design–production interfaces (Jaillon *et al.*, 2009). Transportation regulations are barriers when they limit module sizes (Gibb and Isack, 2003; Bekdik *et al.*, 2016; Choi *et al.*, 2017).

Technical barriers also originate from the clients' lack of technical knowledge of the building process and the effects of their decisions on the process (Halman *et al.*, 2008). For example, clients may not understand when to freeze the design, and they may find it challenging to translate new ways of working to the project's organisation as a whole, which delays the planning process (Pan *et al.*, 2008, 2012; Arif *et al.*, 2012). Clients are being dependent on traditional construction methods when they are not familiar with new techniques or believe that offsite construction is more expensive than conventional construction (Goodier and Gibb, 2007; Mao *et al.*, 2015; Hong *et al.*, 2018).

Economic barriers originate from decision making concerning costs. For example, studies have confirmed that costs are usually the most crucial decision criterion for selecting the building system (Pan *et al.*, 2012; Mao *et al.*, 2015). Also, the scarcity and high price of building land pose economic barriers (Halman *et al.*, 2008). Project-based business models of competitive bidding have been found to inhibit the implementation of systemic innovations (Katila *et al.*, 2018; Hall *et al.*, 2020).

The enablers for PPMOF can also be broadly categorised into social, political, technical and economic categories. Social enablers are related to supply chain integration practices, such as the early involvement of key project parties to enable shared goals and practices between these parties (Hall *et al.*, 2018).

Political enablers are related to decision-making processes. Hedgren and Stehn (2014) studied the impact of clients' decision-making processes on their adoption of PPMOF. The authors suggested that it is essential for the clients to embrace uncertainty and equivocality as a means to overcome social and political barriers for the adoption of PPMOF. As a result, the researchers suggested that decision-making processes should be built on dialogue and relationships between the parties, which enable the creation of multiple meanings and interpretations to interact with decision making. Developers and the government can challenge and influence the decision-making processes of construction parties to foster prefabrication (Gibb and Isack, 2003; Blayse and Manley, 2004). For example, they can bring project parties closer together through policies, improved communication and education and by providing them with best practices and experience (Blayse and Manley, 2004; Goodier and Gibb, 2007; Hedgren and Stehn, 2014; Mao *et al.*, 2015; Hanna *et al.*, 2017; Wuni and Shen, 2019).

Technical enablers are related to the integration of the design, construction and logistics processes (Gibb and Isack, 2003; Goodier and Gibb, 2007; Pan *et al.*, 2008; Bekdik *et al.*, 2016;

Choi *et al.*, 2017; Hamzeh *et al.*, 2017). Currently, the design and construction processes are separate. Prefabrication necessitates a tighter integration between them, for example, by involving the contractors and suppliers earlier in the design process and by freezing the design before starting construction (Zhai *et al.*, 2014). A study showed that the early involvement of mechanical contractors enabled lower costs, shorter schedule and reduced safety incidents (Franz *et al.*, 2013). In general, more design collaboration is needed between designers, suppliers, contractors, clients and architects. PPMOF needs to be considered very early in the design process; otherwise, its benefits cannot be achieved (Pan *et al.*, 2012). Also, it is necessary to plan logistical processes earlier. A system integrator can be acquired to integrate the needed resources into a well-functioning system (Rutten *et al.*, 2009).

Finally, multiparty contracts with financial incentives and target value design (Hall *et al.*, 2018) provide examples of economic enablers for the implementation of PPMOF. For instance, Hanna *et al.* (2017) found that in electrical construction, prefabrication enables contractors to reduce labour wages and expedite the construction process by performing more tasks in parallel. Also, a study has shown that prefabrication, at least in the case of industrialised housebuilding, necessitates a balance between the three concepts – offering, operational platform and market position – of a business model (Lessing and Brege, 2018). Table 1 summarises the social, political, technical and economic barriers and enablers for implementing systemic innovations, such as PPMOF.

Previous studies have shown that social, political, economic and technical barriers and enablers exist for implementing systemic innovations. Next, research regarding the role of value creation and value capture in systemic innovation implementation is discussed.

Value creation and value capture in systemic innovation implementation

Value creation process refers to the activities that create value – such as new knowledge, resources, services, products, processes or user experiences – for customers and other parties (Pulkka *et al.*, 2016; Robinson *et al.*, 2016; Lavikka *et al.*, 2017). The customer is an active participant and collaborates with the supplier in the value creation process, which is dynamic, non-linear and even unconscious (Payne *et al.*, 2008). The activities of the process vary depending on the customers' business processes. However, generally, the process involves activities of collaboratively reviewing value creation opportunities (plan, test and prototype), implementing solutions and developing metrics to assess the success of the value creation. (Payne *et al.*, 2008) Value creation of all organisations is facilitated when trust, mutual awareness and agreement on customer needs exist (Pulkka *et al.*, 2016).

Value capture refers to the organisations' actualised profit-taking, which can be realised, e.g. as reduced costs or increased price, often defined in the contract (Ritala *et al.*, 2013). Autonomous innovations usually enable value capture for single organisations. In contrast, systemic innovations provide opportunities for value capture for several organisations, especially when the organisations' inputs are complementary or their tasks are coordinated (Pulkka *et al.*, 2016).

According to Taylor and Levitt (2004), the *locus* of a systemic innovation is in the linkages between subsystems, whereas the entities affected by the systemic innovation are the various companies. In other words, a systemic innovation is usually not contained within the control of an implementer. Still, it necessitates that other parties within the influence domain of the innovation also take action, i.e. create value, to adjust to the needed changes (Taylor and Levitt, 2004; Alin *et al.*, 2013). Takey and Carvalho (2016) added that it is essential to identify the project parties affected by the innovation and the relationships between those parties to implement a systemic innovation successfully. Examples of systemic innovations that have been studied in the context of construction are BIM (Alin *et al.*, 2013), industrialised housing

Category	Barriers	Enablers
Social	• A risk-averse culture (Pan *et al.*, 2008) • The lack of multi-skilled labour (Goodier and Gibb, 2007; Hamzeh *et al.*, 2017; Zhai *et al.*, 2014)	• The early involvement and colocation of key project participants to enable shared goals and practices (Hall *et al.*, 2018) • Long-term relationships (Lindgren and Emmitt, 2017) • Coordination, collaborative development and reciprocal communication (Kahkonen, 2015) • A process of task sequence alignment, knowledge base alignment, and work allocation alignment (Alin *et al.*, 2013)
Political	• Rigid labour union rules (Said, 2015) • The absence of government regulations and incentives (Mao *et al.*, 2015 • Complex and time-consuming regulative procedures (Halman *et al.*, 2008) • The lack of government incentives (Pan *et al.*, 2012)	• Developers and the government can influence decision-making processes through policies, education and communication of best practices and experiences (Blayse and Manley, 2004; Goodier and Gibb, 2007; Hedgren and Stehn, 2014; Mao *et al.*, 2015; Hanna *et al.*, 2017; Wuni and Shen, 2019) • Decision-making based on dialogue and relationships (Hedgren and Stehn, 2014)
Technical	• Clients' lack of technical knowledge of the building process and the effects of their decisions on the process (Halman *et al.*, 2008) • Clients not familiar with new methods and techniques or believe that offsite construction is more expensive than traditional construction (Goodier and Gibb, 2007; Mao *et al.*, 2015; Hong *et al.*, 2018) • Complex interfaces between subsystems (Jaillon *et al.*, 2009) • The lack of design-production interfaces (Jaillon *et al.*, 2009) • Transportation regulations may limit module sizes (Gibb	• Integration of design, construction and logistics processes (Gibb and Isack, 2003; Goodier and Gibb, 2007; Franz *et al.*, 2013; Pan *et al.*, 2008; Bekdik *et al.*, 2016; Choi *et al.*, 2017; Hamzeh *et al.*, 2017; Taylor and Levitt, 2004; Zhai *et al.*, 2014) • Repetition and standardisation in design solutions (Pan *et al.*, 2012; Mao *et al.*, 2015; Bekdik *et al.*, 2016) • Early planning of PPMOF solutions and logistics (Pan *et al.*, 2012) • System integrators (Pisano and Teece, 2007; Rutten *et al.*, 2009; Robinson *et al.*, 2016; Steinhardt *et al.*, 2020)

(*continued*)

Table 1.
Social, political, technical and economic barriers and enablers for implementing systemic innovations

Category	Barriers	Enablers
	and Isack, 2003; Bekdik *et al.*, 2016; Choi *et al.*, 2017)	• Training programs for personnel and protocols for working with suppliers (Hanna *et al.*, 2017)
Economic	• Price is the most important decision criterion for selecting the building system (Pan *et al.*, 2012; Mao *et al.*, 2015) • The scarcity and high price of building land (Halman *et al.*, 2008) • Project-based business models of competitive bidding (Katila *et al.*, 2018; Hall *et al.*, 2020)	• Relational contracts and target value design (Hall *et al.*, 2018) • Reduced labour wages (Hanna *et al.*, 2017) • A balance between offering, operational platform and market position of a business model (Lessing and Brege, 2018)

Table 1.

(Lindgren and Emmitt, 2017), cellular building products (Kahkonen, 2015) and an MEP solution for radiant heating and cooling (Hall *et al.*, 2018).

Taylor and Levitt (2004) stated that autonomous innovations are implemented quicker than systemic innovations. Systemic innovations require multiple firms to adopt changes, even though the changes would only apply to products or processes. The changes necessary for a systemic innovation may create switching or start-up costs for some project parties and reduce or even eliminate the role of some other parties (Taylor and Levitt, 2004). Thus, value capture from implementing a systemic innovation is not necessarily equal for all project parties (Pisano and Teece, 2007), but all parties should create value to enable innovation implementation.

Long-term relationships best support the implementation of systemic innovations because they provide opportunities for development and learning, which are needed for the diffusion of innovations in inter-organisational construction projects (Lindgren and Emmitt, 2017). The implementation of a systemic innovation necessitates coordination and collaborative development, often through mutual adjustment, which is a reciprocal communication and negotiation process among the parties (Kahkonen, 2015).

Taylor and Levitt (2004) suggested four areas of focus for project managers when implementing a systemic innovation in a project environment. First is reducing the organisational variety of specialist contractors. Second is monitoring the degree of interdependence of work tasks to know where the potential problems lie. The third is reducing boundary strength through an environment that creates inter-organisational trust. Fourth is decreasing the span of the systemic innovation by using systems integrators that integrate resources – such as components, technologies, skills and knowledge – from various specialist firms. Empirical evidence by other researchers also confirms the usefulness of systems integrators (Rutten *et al.*, 2009; Robinson *et al.*, 2016; Steinhardt *et al.*, 2020). These systems integrators are also contractually responsible for the functioning of the system and its project-based production. Thus, the prime contractor organisation may represent the system integrator when responsible for both the design and integration of resources into a system.

Research approach

An interpretive approach was adopted because it is well-suited to understand and describe social processes and complex factors (Schwandt, 1994). According to the interpretive position, knowledge is subjective, contingent on human perception and social experience (Audi, 1998). The interpretive approach was supported by interviews, observation and action workshops (Argyris and Schön, 1989). This data triangulation was used to increase the validity of the research. Two empirical research questions are posed:

RQ1. What are the barriers, enablers, value creation and capture opportunities of project parties when implementing MEP prefabrication in Finland?

RQ2. How to implement MEP prefabrication into the Finnish commercial construction projects?

Interviews and observation for understanding the perspectives of all project parties

Semi-structured interviews focused on identifying the views of all construction project parties and their motives to implement MEP prefabrication. The researchers asked about the enablers, barriers and opportunities for value creation and capture and their interaction when implementing MEP prefabrication. The researchers focused on identifying enablers and barriers from the social, political, technical and economic categories which were identified during the literature search. First, the researchers contacted a few fabricators and general contractors that they knew beforehand. After that, snowball sampling was applied, which means that the already interviewed informants provided the researchers with new prospective interviewees (Biernacki and Waldorf, 1981). Snowball sampling allowed easy and cost-effective access to potential interviewees that had expertise in MEP prefabrication. These individuals would have been hard to identify in other ways. Interviews were conducted until a saturation point was reached, i.e. when no new knowledge related to the interview questions emerged from the interviews. The interviews were conducted from December 2017 to September 2018; altogether, 28 representatives from 23 organisations were interviewed. Table 2 presents the interviewees. The industry interviewees were experienced in the use of PPMOF in single projects, either in residential or commercial construction projects. Each interview was audio-recorded with the permission of the interviewees, and each meeting lasted between 40 and 120 min.

Although MEP prefabrication is not widely practised in Finland, several modular solutions exist on the market. Examples of prefabricated MEP modular solutions include technical rooms; prefabricated pipeline manifolds; corridor elements such as ductwork, pipework and electrical cables in MEP racks; and bathroom pods that incorporate pipework, electrical cables and ductwork. The corridor elements can be described as prefabricated multi-service modules that are usually insulated, pressure tested and mounted in the ceiling or under the floor. To better understand these prefabricated MEP modular solutions and their production and assembly processes, circumstances and challenges, the authors visited factories producing MEP racks and bathroom pods as well as sites using these solutions to observe their on-site logistics and installation.

The interview data analysis followed the recommendations of Miles and Huberman (1994). After each interview, a transcription service provider transcribed the interview verbatim. The transcriptions were read by the researchers to gain a preliminary understanding of the data. Then, the transcriptions were encoded, and quotes were chosen and analysed using a qualitative data analysis software application. Six codes were used in the analysis:

The number of representatives	Type of organisation	Title of the interviewee (s)	Length (in minutes)
Five client representatives	Business	Senior vice president	54
	Government	•Specialist •Director of construction	47 53
	University	•Director of construction •Premise manager	65 49
	An association representing residential and commercial property owners	Member of a construction commission	78
An architect	Architectural firm	Architect	55
A designer	MEP design consultant	Technology director	66
Three construction representatives	•General contractor A •General contractor B	•A's production unit manager •B's project manager and MEP manager	62 98
	Construction company	•Business unit manager •Project manager •MEP manager	87
A MEP contractor	MEP contractor	Mechanic	40
Eight fabricators	•Bathroom module fabricator C •Bathroom module fabricator D	•C's project manager and two co-founders •D's operations director	108 68
	Machine room fabricator	Project manager, CEO	79
	MEP system provider	Head of projects	72
	Precast concrete producer	Design manager	73
	MEP fabricator	Production manager and chief engineering officer	120
	Modular MEP mounting systems	Key account manager and project manager	87
	Pipe fabricator	Production manager	68
Two union representatives	MEP union	Branch manager	64
	Construction union	Negotiations manager	48
A research representative	University	Professor	61

Table 2. Interviewees

(1) enablers of MEP prefabrication;
(2) barriers to MEP prefabrication;
(3) value creation;
(4) value capture;
(5) MEP prefabricated solutions; and
(6) other interesting themes.

Codes 1–4 were selected based on the literature, and Codes 5 and 6 emerged during the analysis process. After that, the researchers analysed the barriers and enablers for MEP prefabrication. Then, the researchers analysed the value creation and capturing opportunities. After these analyses, the researchers studied all four constructs in combination since they cannot be studied in isolation as they collectively contribute to the current situation of MEP prefabrication usage in the Finnish construction context. Finally, the researchers aimed to identify interaction patterns of these constructs, i.e. how the barriers and enablers interact with the opportunities for value creation and value capture. Two researchers conducted the data analysis, and the analysis findings were compared to receive a consensus on the meaning and relevance of each data point.

Action workshops to support the implementation of mechanical, electrical and plumbing prefabrication

Action workshops focused on discussing MEP prefabricated solutions, verifying interview findings on barriers and enablers and understanding how to support the implementation of prefabrication. Action workshops are designed to meet a specific need, and they usually last a couple of hours and involve strategically selected participants in an interactive dialogue (Pettigrew, 1990). Participatory action-oriented research is based on the assumption that the interpretation of the behaviour of human beings is more valid when human beings participate in building and testing behaviours (Argyris and Schön, 1989).

Four action workshops were organised between February and June 2018. Altogether, 47 participants, representing designers, fabricators and general contractors from 14 different companies, participated in the workshops. The participants were selected based on their expertise in building projects and prefabrication. The researchers were responsible for setting the agenda for every workshop, facilitating the discussion between participants and making detailed notes on the conversation.

Findings and discussion

This section is divided into three subsections. The first two sections answer the first empirical research question on the barriers, enablers, value creation and value capture of all project parties when implementing MEP prefabrication in Finland. The third section answers the second empirical research question on how to implement MEP prefabrication into the Finnish construction projects by analysing the interaction patterns of the identified barriers, enablers, value creation and capture in combination. The patterns help understand what factors have led to the low adoption of MEP prefabrication and how to overcome them.

Barriers and enablers for implementing mechanical, electrical and plumbing prefabrication

The interview analysis revealed social, political, technical and economic barriers and enablers for implementing MEP prefabrication, which confirm earlier findings (Zhai *et al.*, 2014; Hanna *et al.*, 2017; Hall *et al.*, 2018). For example, a social barrier to MEP prefabrication is that the architects and different MEP designers are still used to designing one-of-a-kind products. In contrast, prefabrication, especially the use of modules such as bathroom pods, has been found to necessitate repetition and standardisation in design solutions, which are technical enablers (Pan *et al.*, 2012; Mao *et al.*, 2015; Bekdik *et al.*, 2016). Some informants, especially those who have already used prefabrication, suggested that standardised design solutions could prevent many quality issues and reduce problem fixing and rework because well-coordinated design models can communicate standard solutions. According to one general contractor, "Technically, it would be easy to agree on design standards on pipes and ducts and interfaces between the trades".

MEP designers and trade contractors face economic barriers that originate from the current project-oriented business model, which is the traditional model for building one-of-a-kind buildings (Lessing and Brege, 2015; Katila *et al.*, 2018; Hall *et al.*, 2020). The current business model entails contract boundaries, forcing a rigid division between MEP design and installation and between MEP trade contractors. One example of an MEP prefabricated product is a common hanger system where all MEP hangers are prefabricated and installed in one MEP rack. This system would mean that only one trade contractor is required.

However, the implementation of this system is against the current business model, which is based on the volume of materials and assemblies. Each trade contractor, performing a part of the MEP work, counts its hangers and their assembly work into its contract, in contrast to business models emphasising integrated product-orientation where a trade takes responsibility for the whole scope of work using a prefabricated product system (Lessing and Brege, 2015). The reason for this business model originates from the labour union agreements in which MEP workers must be paid by piece rate, even though the workers would only be installing pre-assembled products. With MEP prefabrication, labour unions want to ensure that their members will keep their jobs at the same compensation levels. Rigid labour union agreements have already been found as a political barrier for prefabrication in an earlier study (Said, 2015).

The client and the general contractor face technical barriers, such as the lack of PPMOF procurement knowledge. For example, the clients and general contractors tend to procure each building part separately, which does not support the procurement of, for example, a prefabricated wall system that includes sub-component systems of MEP. An MEP fabricator explains: "MEP should be seen as one package to be procured and not as separate building parts. The general contractor and the client should change their current procurement practices". The lack of PPMOF procurement knowledge was not found as a barrier in the literature study, but clients' lack of knowledge of the building process has been found as a technical barrier (Halman *et al.*, 2008).

Based on the interviewees, the price is the dominant factor in the clients and contractors' bidding process, confirming earlier findings (Pan *et al.*, 2012; Mao *et al.*, 2015). The current view in Finland is that direct costs are higher in prefabrication. Many respondents were not sure whether the benefits from a shorter schedule of prefabrication could be financially realised. The comparison between procuring building parts separately versus procuring a prefabricated wall system, including MEP, is not straightforward. It requires PPMOF procurement expertise because the benefits of prefabrication are spread throughout the entire construction supply chain and realised, for example, as quicker on-site installation and lower costs from logistics and material waste.

Some MEP contractors realised that MEP prefabrication would enable them to focus on professional, value-adding assembly work instead of carrying materials and doing other low-value tasks, which are dominant in current practices. Additionally, other MEP contractors wondered whether the adoption of prefabrication would lead to a reduction in employees, which would provide a significant amount of savings for the construction firms. An MEP contractor explained the political barrier that his company faced: "If everything is prefabricated, it means less work to our plumbing employees [members of a labour union]. The MEP workers' union agreements do not support MEP prefabrication". However, no interviewee could provide a quick solution to the problem of union agreements. Still, many thought that prefabrication would eventually "win the battle", and workers belonging to a different union are already available, so the union agreement including the same piece work rate for both prefabricated and traditionally installed work would need to change at some point.

The lack of a shared prefabrication strategy was seen as a significant (social, and partly technical) barrier to implementing prefabrication. The different contractors, such as those involved in mechanical, plumbing, electricity and fireproofing work, do not share a common strategy for implementing MEP prefabrication. As a remedy, the MEP designers and contractors suggested relational contracts, such as alliance models, to enable collaboration between the trades in the early phase, which has been found to be an economic enabler for prefabrication (Hall *et al.*, 2018). One designer shed light on the benefits of alliance models:

> In an alliance, we can think about the benefit of the project, instead of only my direct costs, because we have a common goal and I am paid for my costs. Thus, we can collaboratively decide on how to implement prefabrication in the project.

A technical barrier is that the MEP designers do not possess capabilities for modelling MEP on a level of detail that would support MEP prefabrication or the installation of MEP prefabricated building parts. In Finland, the MEP designer is responsible for the rough MEP design, and MEP sub-contractors install MEP without an installation-level design. One MEP designer, however, suggested that designers could model installation-level BIM in collaboration with fabricators: "We could design more detailed-level BIM through cross-trade design collaboration between the designer, the MEP contractor and the fabricator".

The interviewees estimated that MEP contractors would not have sufficient capabilities for modelling detailed design, but MEP design offices could develop that knowledge more efficiently. The same division of work has been previously observed in concrete element prefabrication. The interviewees were also sceptical whether current Finnish MEP contractors would invest in prefabrication facilities; instead, MEP fabricators would mostly be new companies without a strong history in on-site operations.

Some informants argued that clients often require changes in design during the project, and this disturbs the prefabrication process. Thus, the design should be frozen earlier than in traditional construction to leave time for production planning, fabrication and on-site delivery, confirming the results by Pan *et al.* (2012).

The interviewees were concerned that Finland might have a shortage of experts in implementing prefabrication. As a solution, they advised that universities and technical schools should teach prefabrication in their curriculums. Some informants suggested that the government should set some targets and strategies for encouraging the adoption of prefabrication in the industry, which would push them toward more industrialised production. Earlier studies have also suggested this solution (Hedgren and Stehn, 2014; Mao *et al.*, 2015; Hanna *et al.*, 2017; Wuni and Shen, 2019).

Value capture and value creation of each party

The findings on value capture and value creation show that each party in the construction supply chain could both create and capture value from MEP prefabrication. However, the interviewees agreed that MEP prefabrication is most beneficial to the clients and general contractors. The clients receive a better-quality facility in a shorter period, which is a result supporting earlier findings (Wong *et al.*, 2017), while the general contractor captures value from reduced throughput time and fewer logistics. However, other parties can also capture value through the implementation of MEP prefabrication. MEP contractors benefit from improved worker safety, following earlier results by Pan *et al.* (2012). In contrast, MEP designers benefit from more revenue as they can add more scope into their design contracts. Prefabrication could potentially also increase design work for MEP designers as they need to provide more detailed designs. Fabricators would benefit from more MEP fabrication as the market develops, and they would be allowed to invest in more advanced technology.

The fabricators thought they could create value for the project by providing better quality products with less material waste at a reduced price and schedule. At its best, the general contractor can realise the maximum value of the project from prefabrication by ensuring efficient work throughout the construction supply chain. The general contractor can act as a change agent by emphasising prefabrication in MEP procurements. Other parties also create value for the project in various ways when implementing MEP prefabrication. The client can provide facility management know-how to MEP designers and work as a change agent in implementing best practices for MEP prefabrication.

The MEP designers can create value by providing an installation-level BIM model and consultation services during the design and construction process. The MEP contractors, in return, can contribute their knowledge of site installations, especially when applying module designs. When all the project parties work towards the common goal of MEP prefabrication, they can reduce material waste and improvisation in on-site work. At its best, MEP prefabrication can help in the production of a high-quality facility for the client at a fast pace and fixed cost.

Table 3 summarises the barriers, enablers, value creation and value capture of construction project parties when implementing MEP prefabrication.

Suggestions for implementing mechanical, electrical and plumbing prefabrication into the Finnish construction projects

The current volume-based business models, partly originating from trade unions' agreements for prefabrication payments, and non-collaborative contracts, where piece work payments are the same for prefabricated and non-prefabricated products, restrict fair value capturing from prefabrication. They also reduce the urge to implement prefabrication in construction ecosystem. Trade unions have demanded that MEP tradesmen be paid the same compensation per unit when applying prefabricated products, even though this work takes less time than the use of conventional products. Thus, while clients and contractors may be capturing value through a reduced schedule, they have not captured value in the form of reduced costs. On the contrary, the labour costs of an MEP contractor would increase because they have to pay for labour related to prefabrication without labour cost savings related to on-site installation. Business models based on competitive bidding, union agreements, and contract boundaries as barriers for prefabrication confirm earlier findings (Pan *et al.*, 2012; Mao *et al.*, 2015; Bekdik *et al.*, 2016).

Following earlier studies, business models necessitate a balance between the offering, operations and market position (Lessing and Brege, 2015, 2018; Hall *et al.*, 2020). For example, a company's offering can include several types of prefabricated MEP products, such as modular heating systems that can consist of boilers, pumping stations, substations, planning tools, management information systems and automation equipment. The operations required to produce this offering need to be efficient. In the case of modular heating systems, the MEP designers and MEP contractor need to collaborate early on to integrate design, assembly and logistic processes. Finally, the company's market position, i.e. the role of the company in the building process, needs to match with the offering and operations. At this moment, the market position of companies offering prefabricated MEP products is challenging, due to the trade union agreements. Thus, the trade unions are in a significant market position in enabling the value capture of several parties. If the unions changed the business rules for applying MEP prefabricated products, more prefabricated products would likely be used. Then, clients and contractors would capture value through reduced costs and schedule, improved product quality and site productivity as well as fewer logistics. Also, clients would capture value from improved usability and upgradability of facilities.

MEP contractors might want to create value by providing their know-how of installation processes to the product designers so that the products would be better designed for assembly. Thus, the MEP contractors would capture value from additional consulting service fees, project efficiency and improved worker safety, as suggested by Franz *et al.* (2013). MEP designers could create value by learning the capabilities needed for detailed level design, which would enable them to capture value through more revenue from installation-level design work. In the end, MEP contractors could capture value also through the execution of more projects. All these actions

Table 3.
The views of construction project parties towards MEP prefabrication in Finnish construction projects

Stakeholder	Barriers	Enablers	Value creation opportunities	Value capture opportunities
Client	*Social*: • Few prefabrication solution providers *Technical*: •Lack of knowledge about the timing of freezing the design •Lack of PPMOF procurement knowledge *Economic*: •Price as the main bidding criteria	*Political*: •The government initiated development programs *Technical*: •PPMOF procurement expertise *Economic*: •Relational contracts	•Know-how in facility management •Change agent	•Shortened schedule and reduced cost •Improved quality of the end product •Improved usability and upgradability of facilities
Designers, especially MEP designers	*Social*: •Used to designing one-of-a-kind products •Industry's resistance to change *Technical*: •Lack of capabilities for detailed level design *Economic*: •Business models, contract boundaries	*Social*: •Design collaboration with MEP sub-contractor •Changes in sub-contractor responsibilities *Political*: •Changes in trade union requirements *Technical*: •Repetition and standardisation in design solutions *Economic:* •Changes in business models/contract boundaries •Relational contracts	•Installation-level BIM model •Consultant services during design and construction	•More revenue through installation-level design work
MEP trade contractors	*Social*: •Tight schedule •Risk-averse culture •No shared implementation strategy *Political*: •Unions' agreements for prefabrication payments *Technical*: •Lack of installation-level designs •Lack of repeatability in design *Economic*: •Business models, contract boundaries	*Social*: •Agreement on installation-level BIM *Technical*: •Workshops for prefabrication *Technical*: •PPMOF procurement expertise •Showcases of good practices for prefabrication *Economic*: •Relational contracts	•Know-how of installation process	•Project efficiency •Improved worker safety
General contractor	*Technical*: •Lack of MEP prefabrication procurement knowledge *Economic*: •Price as the main bidding criteria		•Change agent •The realisation of value from prefabrication	•Reduced throughput time •Site productivity improvement •Fewer logistics
Fabricator	*Social*: •The market is missing •Detailed MEP design made too late *Technical*: •Design revisions	*Social*: •Clients' or governments' requirements *Technical*: •Early design freeze •Better references	•Less material waste •Better quality •Reduced schedule	•Market development •Possibility of investments and international markets

could enable fabricators to capture value from market development and eventually invest in new product development.

Clients and general contractors lack PPMOF procurement knowledge. They have too narrow bidding criteria and use price as the main bidding criteria, which lead to the procurement of each building part separately, instead of purchasing MEP as one package. This lack of value-based procurement acts as a potent inhibitor for prefabrication. Clients and general contractors lack awareness of the possible cost savings when applying MEP prefabricated products, confirming earlier findings by Blismas and Wakefield (2009). These findings confirm that clients play a crucial role in enabling MEP prefabrication, a systemic innovation (Gibb and Isack, 2003; Gambatese and Hallowell, 2011).

The fabricators could advertise their prefabricated MEP products to owners and contractors so that the owners could learn about the value capturing opportunities of these products and thus not always use price as the main bidding criteria. The clients may not receive the reduced costs of MEP prefabrication in the form of a cheaper MEP subsystem. Still, the costs of the whole project will be reduced through the quicker on-site installation, lower logistics costs, less material waste and fewer worker injuries.

The traditional practice of designers designing one-of-a-kind products and clients not freezing the design early enough leads to a rigid division between MEP design and installation and between separate MEP trade contractors. The division leads to an unclear value creation between the parties, instead of collaborative value creation, where all parties know how each party is contributing and increasing the share of the business to all parties. These results confirm earlier findings that the clients need to be aware of the right timing for making decisions, especially when to freeze the design to ensure that detailed design can begin and expenses due to late design changes are avoided (Gibb and Isack, 2003; Arif *et al.*, 2012; Pan *et al.*, 2012). MEP designers, on the other hand, should use standardised design solutions or collaborate with MEP subcontractors during the design of MEP, which are new findings that have not been discussed in previous studies on PPMOF. Educating is one solution for increasing the awareness of the prefabrication design process, as suggested by Halman *et al.* (2008).

The general contractor could create value by acting as a change agent, or as a system integrator as suggested by several studies (Rutten *et al.*, 2009; Robinson *et al.*, 2016; Steinhardt *et al.*, 2020), to ensure that different trades agree on the work done in trade boundaries and by taking an active role in the coordination of prefabricated systems. When MEP contractors and general contractors learn how to shorten the project schedule using MEP prefabricated products, they will likely start procuring these products. Thus, the market for MEP prefabricated products would grow, leading to more value-creation opportunities for several parties. MEP contractors also complained that no shared implementation strategy exists. As a solution, they suggested that the construction association could organise prefabrication workshops, wherein key parties would discuss and agree on the use of PPMOF.

Figure 1 illustrates the interaction patterns on how barriers lead to uneven value capturing, lack of value-based procurement and unclear value creation between MEP design and installation, which maintain the status quo of low MEP prefabrication usage in the Finnish construction projects. The figure shows the enablers leading to fairly shared value to all parties, procurement of value and collaborative value creation, which increase the usage of MEP prefabrication. Hence, this study confirms earlier findings by Pulkka *et al.* (2016) that value creation and value capture play an essential role in systemic innovation implementation.

Previous studies have not considered the barriers of all parties, but chosen, instead, to focus on a single party, such as the electrical contractor (Said, 2015; Hanna *et al.*, 2017). One contribution of this study lies in studying the barriers, enablers, value creation and capture of all parties in combination and pointing their interaction patterns, which have led to the situation where

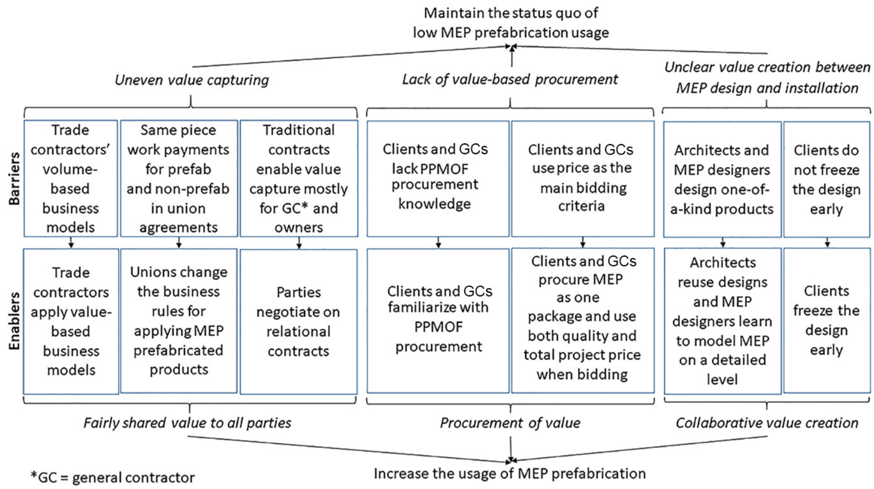

Figure 1.
The interaction patterns of barriers, enablers, value creation and capture in the Finnish construction projects

complex MEP prefabricated products, affecting the work of several construction project parties, are scarcely applied.

Previous studies have emphasised the importance of coordination and collaboration for the implementation of systemic innovations (Taylor and Levitt, 2004; Halman *et al.*, 2008; Alin *et al.*, 2013; Kahkonen, 2015). This study adds new knowledge by demonstrating that the identification of barriers and their interaction with enablers and the opportunities for value creation and capture lay a baseline for suggestions on how to implement a systemic innovation.

Conclusions

The study stresses the importance of enabling value creation and capture of all construction project parties when implementing a systemic innovation. The study implies that the implementation of systemic innovations in construction necessitates the identification of barriers, enablers and the opportunities for value creation and value capture of all affected parties and their interaction patterns to lay a baseline for needed changes. Focusing first on analysing each party of the construction project one at a time helps in revealing hidden agendas, mistrust and lack of capabilities among the parties, even if they all agree that the industry as a whole would benefit from the innovation. Instead of pushing one implementation strategy to all markets, understanding the baseline for changes helps to fine-tune the needed steps towards the systemic innovation in specific market circumstances.

Finnish commercial construction projects are still in the early phases of adopting MEP prefabrication. This study adds knowledge on implementing MEP prefabrication in Finland and countries with similar low initial adoption rate, strong labour unions and fragmented roles of parties in the construction supply chain. Three practical implications can be recommended. First, discussion with the unions should be initiated to find a win-win situation in which workers can capture value without preventing value capture of other parties. Second, the clients should change their current procurement and bidding practices of purchasing the cheapest separate building parts to purchasing MEP as one package and use both quality and total project price when bidding, which better supports MEP prefabrication. Third, the use of standardised design solutions, early design freeze and collaboration between MEP designers and assemblers resemble practices that could better integrate design and construction towards the use of MEP prefabricated products.

The empirical data collected in the Finnish construction context are limited. Further data collection in other countries would allow for conducting a comparative case study of barriers and enablers and their connection to opportunities for value creation and capture between similar but also different contexts to verify the generalizability of the findings. The implementation of MEP prefabrication has already taken place in some countries, such as the UK, the USA, Australia and China. Hence, future research could focus on understanding how barriers have been mitigated in those countries, and how the opportunities for value creation and capture have been realised.

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