

Implementing solar photovoltaic systems in buildings: a case of systemic innovation in the construction sector

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Abstract

Purpose – This paper aims to explore the process of implementing solar photovoltaic (PV) systems in construction to contribute to the understanding of systemic innovation in construction.

Design/methodology/approach – The exploratory research presented is based on qualitative data collected in workshops and interviews with 76 construction- and solar-industry actors experienced in solar PV projects. Actor-specific barriers were identified and analysed using an abductive approach.

Findings – In light of established definitions of systemic innovation, the process of implementing solar PV systems in construction involves challenges regarding technical and material issues, competencies, and informal and formal institutions. The specificities of this case highlight the necessity of paying attention to details in the process and to develop knowledge of systemic innovation in construction since the industry's involvement in addressing societal challenges related to the energy transition will require implementing such innovations much more in the future.

Practical implications – New knowledge of solar PV systems as an innovation in professional construction is collected, enabling the adaptation of management strategies for its implementation. This knowledge can also be applied generally to other challenges encountered in highly systemic innovation implementation. Solar industry actors can gain an understanding of solar-specific challenges for the construction industry, challenges for which they must adapt their activities.

Originality/value – The exploration of actor-specific experiences of solar PV projects has resulted in a novel understanding of this specific innovation and its implementation. The findings illustrate a case of a high level of systemic innovation and the need to use a finer-grained scale for classification when studying innovation in construction.

Keywords Innovation, Barriers, Construction, Implementation, Systemic, Solar photovoltaic

Paper type Research paper



Introduction

Given the societal challenges following the climate crisis, ensuring a transition to sustainable energy supply has become necessary. The European Union has set the goal of being climate neutral by 2050 in the “European Green Deal” (EC, 2020). Given that the energy demand in buildings constitutes 30% of the total energy demand worldwide (IEA, 2021), energy-related change must be pursued in the construction sector. Besides increased energy efficiency in buildings, securing an energy supply from renewable energy sources is central to the energy transition.

One such renewable energy source is solar energy. Solar photovoltaic (PV) systems contribute to buildings’ sustainability by reducing the need for electricity from the grid. However, the diffusion of PV systems installed in the built environment (BEPV) in Sweden has historically been slow (Lindahl *et al.*, 2021) and has therefore been subject to research. The diffusion of PV in Sweden has been studied at different levels of analysis, ranging from policy-related problems of PV diffusion considered within a technology innovation systems framework (Andersson *et al.*, 2021; Palmblad *et al.*, 2008; Palm, 2015) to the mapping of factors influencing adoption in the domestic (Palm, 2016; Palm, 2018) and commercial markets (Wong and Cronin, 2019; van Oorschot *et al.*, 2021). Some scholars have studied PV as part of the construction industry (Wong and Cronin, 2019; Curtius, 2018), identifying challenges due to a lack of BEPV standardization in the industry. However, there is a gap in studies addressing the specific process of implementing solar PV systems in the professional construction industry. Solar PV is an innovation in the construction context that involves many actors and many aspects to handle and coordinate when implemented in a building. For example, its implementation affects clients’ investment and return calculations, designing consultants’ specifications, contractors’ working methods and actors linked to electricity production and supply. In the professional construction context, innovations are implemented through projects based on inter-firm cooperation in unique settings. The project-based setting of construction production and the temporary constellation of diverse actors with different organisational belongings is the root of challenges regarding innovation implementation (Eriksson, 2013; Rose *et al.*, 2019; Orstavik, 2019). For example, cooperation between actors is shown to be challenging when actors are tasked to do something new, e.g. jointly implementing an innovation (Havenvid, 2015). Implementing innovations entails changes in both institutionalized work methods and end products (Rogers, 2003). Thus, to understand PV implementation, it is necessary to study its process in the specific construction context and, thereby, the actor-related challenges.

To address these construction-related specificities and actor-specific challenges, by planning activities and adapting resources to implement a specific innovation, it is central to know to what extent change is needed (Slaughter, 1998; Manley, 2008). The necessary change can be understood by categorizing the specific innovation (Slaughter, 1998; Taylor and Levitt, 2004), for example, as systemic innovation. In this study, systemic innovation is viewed as when the innovation requires multiple firms to change their design and prefabrication practices, and processes and when its implementation entails coordination between the actors linked to the system where the implementation occurs (Taylor and Levitt, 2004; Lindblad and Karrbom Gustavsson, 2021; Hall *et al.*, 2018). Also, systemic innovations can change the structure of cooperation and the boundaries between the actors in a network to a greater extent than less-complex innovations (Taylor and Levitt, 2004). Systemic innovation can entail different levels of complexity, ranging from a few to many involved actors.

Research shows that the coordination of systemic innovation implementation is greatly dependent on the innovation’s complexity, the implementation setting, and that the level of

systemic involvement affects how difficult the innovation will be to implement (Orstavik, 2019; Lindgren, 2018). Evidently, the more aspects an innovation involves and the more actors required for its implementation, the greater the coordination effort must be. In addition, systemic innovation cases differ in specificities, so the literature on systemic innovation implementation identifies various process factors that merit consideration. Given the above definition of systemic innovation and the characteristics of PV implementation in construction, BEPV is, in this study, considered a systemic innovation. Furthermore, climate-related social challenges will increasingly require systemic innovation in construction. Therefore, the knowledge developed here receives a vital role in preparing for future significant changes where buildings are transformed into more than just passive structures. To advance BEPV implementation in construction and to improve the understanding of systemic innovation in construction, further understanding is needed. To improve this understanding, the BEPV implementation process is explored by mapping specifics of BEPV implementation, guided by the following research question:

RQ1. What characterises BEPV implementation in the professional construction setting?

The rest of this paper describes implementation as part of the innovation diffusion and characterizations of systemic innovation in construction. After that, the BEPV context, the method, and the study design are described. The findings and analysis are presented in an ensuring section. Finally, the results are discussed, conclusions are presented and further research directions are proposed.

The innovation context

In this study, innovation is studied in the construction industry context. Focus lies on the implementation process, and as described above, this process is organised into projects. To position this focus, research on implementation based on innovation diffusion theory is described below. Thereafter, to enable a comparison of BEPV to studies of other systemic innovations, examples from the literature on such in the construction context are given.

Innovation implementation in diffusion theory

Innovation implementation is part of the innovation process. Implementation follows the decision to adopt, as described by Rogers (2003). For an innovation to diffuse, several separate decisions to adopt a particular innovation over time are required (Rogers, 2003). Rogers (2003) differs between the adoption process for individuals, within organisations and in networks. In networks, the work of Rogers (2003) deals with key aspects regarding the effects of change agents and opinion leaders for innovation to diffuse through repeated implementations. The implementation is when an innovation is put to use by an individual or “other decision-making unit”. The way to “put to use” depends entirely on the context. In construction, it takes place in inter-organisational and temporary projects, and the decision-making unit is the construction client. Within projects, innovation implementation involves changes in behaviour by involved actors. It is in this stage that problems emerge since uncertainty about the innovation still endures (Rogers, 2003, p. 179). Therefore, the implementation process consists of problem-solving and information-seeking, and in an organizational setting, concerned actors are often other than the decision-maker. Within the organizational setting of work in construction, the client, as a decision-maker, is engaged with and collaborates with the implementers and is thus a project partner in the design and

construction phases. It is in this implementation part of the diffusion process that this study focuses on identified problems for BEPV in construction projects.

Systemic innovation in construction

Studying systemic innovation in construction is central to the industry's development since the production is organised through inter-organisational cooperation, following the view of systemic innovation in this paper, and since systemic innovation is central to increasing efficiency in the industry (Shabanesfahani and Tabrizi, 2012). It is important to be aware of challenges (Larsen, 2011) and to adapt the project coordination when implementing systemic innovation in construction (Hedborg Bengtsson *et al.*, 2018). General descriptions of systemic innovation and categorising are fundamental to this coordination.

As a starting point, the literature relating to barriers and factors influencing systemic innovation in construction is reviewed (see Table 1). The term "systemic innovation" is not used throughout the listed literature, but the various descriptions of the studied innovations fit the definition of systemic innovation used in this study. For example, the examples given of systemic innovations all have inter-organizational effects on the construction process (see, for example, Lindgren and Emmitt, 2017).

Blayse and Manley (2004) explored enablers of and barriers to construction innovation and listed the following essential factors for firms and policymakers to consider when setting strategies and policy:

- clients and manufacturers;
- the structure of production;
- relationships between individuals and firms within the industry and between the industry and external parties,
- procurement systems;
- regulations/standards; and
- the nature and quality of organizational resources.

Study	Factors
Blayse and Manley (2004)	Clients and manufacturers, the structure of production, relationships between individuals and firms within the industry and between the industry and external parties, procurement systems, regulations/standards, and the nature and quality of organizational resources
Vennström and Eriksson (2010)	Attitudinal, industrial and institutional
Taylor and Levitt (2004)	Organizational variety, degree of interdependence, boundary strength; requires extra coordination of inter-organizational cooperation and additional corporate strategy of integration
Lindgren and Emmitt (2017)	Recognition and tradition, external drivers, complexity in managing the system and active clients, financial aspects and definition level
Hemström <i>et al.</i> (2017)	Interrelated regulative, normative and cognitive rules that contribute to path dependency
Samuelson and Björk (2013)	Implementation requires strong decision-makers, strong process owners and standardization

Source: Author's work

Table 1.
Factors influencing
systemic innovation
in construction

Their conception of innovation in construction is described by product innovation, which involves actors in inter-organisational collaboration, which equals this study's definition of systemic innovation. Other factors affecting construction production innovation are linked to attitudinal, industrial, and institutional issues (Vennström and Eriksson, 2010). Vennström and Eriksson (2010) considered client-perspective challenges facing innovation in the implementation phase, focusing on industry structure and client ability. Scholars have also shown that implementing systemic innovation in construction greatly affects organizational variety, degree of interdependence, boundary strength and span (Taylor and Levitt, 2004). The same study also showed that implementing systemic innovation in construction requires more strategy and coordination than do other types of innovation, mainly due to the project-based setting of production. Lindgren and Emmitt (2017) identified interacting factors that affect systemic innovation diffusion in construction: recognition and tradition, external drivers, complexity in managing the system and active clients, financial aspects and definition level. These factors show that the characteristics of production in construction and the level of systemic characterization are central to managing innovation implementation in the sector. In addition, Hemström *et al.* (2017) showed that barriers to innovation in construction are linked to regulatory, normative and cognitive rules that contribute to path dependency and actors' resistance to change.

Information technology (IT) innovations in construction concern the transition to electronic documents for planning, establishing system communication, cooperation and long-term management (Samuelson and Björk, 2013). IT innovations affect many actors who need to make new connections and forge cooperation strategies in new ways due to the introduction of these innovations. However, IT's systemic character is kept within bounds as it is limited to solution-oriented digital tools and protocols. Research on IT innovations, such as building information modelling, often focuses on single applications with more or less systemic effects. Although not explicitly, the description of Samuelson and Björk (2013) reveals that the studied IT innovations are systemic since their applications build on multiple relationships between actors and affect many over long periods. Their study shows that implementing IT innovation in construction requires strong ownership of the task and is hampered by a lack of standardization.

Hence, knowledge of systemic innovations cannot be fully generalized, and the literature cannot be linked to the challenges encountered in the management of all systemic innovations. To achieve sufficient knowledge of systemic innovation in construction, differences between systemic innovations must be discussed. Systemic innovation must therefore be considered in greater detail if we are to improve our knowledge, meaning that there is a need to study the requirements for and implications of specific systemic innovations.

Research setting

Within this study, data were collected through workshops and interviews with actors from the construction and PV industries in Sweden. The BEPV implementation process was thereby described from actor-specific perspectives. The data were analysed abductively, and the findings were compared to the literature on systemic innovation in construction.

The context for solar photovoltaic in construction

BEPV projects can be conducted in construction projects for new buildings, within renovation projects or as stand-alone installation projects on existing buildings. This study was limited to professionally assigned commercial construction projects implementing solar PV systems. Solar PV projects in the private household market were excluded since these

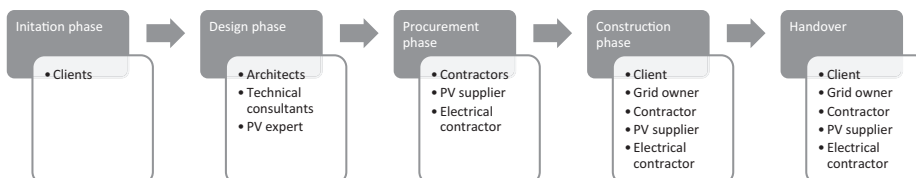
are organized quite differently from commercial construction production. A construction project installing BEPV is intended to create end-user value by building and installing a solar PV system that delivers electricity to a building and the electrical grid following specified functions and requirements.

A BEPV project is typically initiated by a client organization, for example, a real estate company. The client organization commissions construction actors from professional disciplines, such as builders, architects, consultants and contractors, to ensure necessary project functions. The actors have different assignments and tasks, are engaged at different project stages and serve different purposes. In BEPV projects, the constellation of actors is adapted to the project's aim, and PV experts might be included. In the design phase of a construction project, the client or the client's representative leads the design work, typically conducted by architects and technical consultants and, in this case, perhaps a PV expert as well. In the following procurement phase, a contractor, PV supplier and electrical contractor are added to fulfil the client's bid, following the design documents. Together with the grid owner, a contractor, PV supplier and electrical contractor are also involved in the ensuing construction phase, in which the production of the construction product occurs. They are also part of the handover, which ends the construction project. The BEPV implementation process with the associated actors is illustrated in Figure 1.

Research design and method

The study aim required an exploratory approach for which qualitative methods were chosen (Creswell, 2003). The case study approach was chosen since the implementation process is a phenomenon that can be explored through one or more cases over time (Yin, 2014). The phenomenon of interest occurs in multiple construction projects, so the data collection method was chosen to gather information from actors with multiple BEPV experiences to gain accumulated knowledge.

BEPV was studied as a case of systemic innovation implementation, and to explore this phenomenon, actors with experience from BEPV projects in the Swedish commercial construction sector and solar industry involved in implementation processes were invited to workshops and interviews. The actors were addressed through industry, and actor-specific networks and trade organizations were assessed to constitute a majority of professional actors of focus in the study. The selected actors for the workshops represented actors from actor groups of architects, clients, PV experts, grid owners, contractors, PV suppliers, technical consultants, and electrical contractors. The informants' experiences were handled as actor-specific regarding tasks related to the implementation of solar PV and as representing the specific discipline. The informants were selected by ensuring that actors



Source: Author's work

Figure 1.
Construction project
for PV
implementation

had experience in BEPV projects, and the invitation was open until a certain number of registrations was reached.

Data on the process of BEPV implementation were collected via workshops and interviews since they enable a deep understanding of experiences and collective phenomena (Jingmond and Ågren, 2015). To explore the BEPV characteristics and enable discussions about the implementation process, the data collection was designed to explore different BEPV-related barriers. The focus on barriers enabled the exploration of the characteristics of the BEPV implementation process.

The actor-specific workshops and interviews enabled a detailed picture of actor-related problems. Furthermore, the division into actor-specific groups enabled insights into separate disciplines and avoided hierarchical influences or other subconscious impacts during the data collection. The workshop design was intended to promote discussions of BEPV barriers, capturing experiences and combinations of information and opinions (Mohammed and Ringseis, 2001). The interviews were substitutes for the last two workshops, cancelled when social restrictions were implemented due to the COVID-19 pandemic. The interviews followed the same structure as the workshops, as further described below. Actors from construction-specific disciplines and PV-related actors, traditionally not part of the construction industry but involved in BEPV projects (e.g. PV suppliers and grid owners), were subjects in the data collection. PV experts were included in this study, although the involvement of PV experts varies between projects. They are involved in various project phases, or they might not be engaged at all.

Table 2 lists the targeted actor groups, the duration of the data collection, and the number of participants. Due to the high number of positive responses to invitations to participate in the study, the participating clients were divided into two groups, i.e. Client I and Client II, following the order of registration. The data from these two workshops were merged following the sessions.

The workshops and interviews were conducted in four steps, as shown in Figure 2. To identify barriers to implementing BEPV, the data collection started with an open question asking participants to individually identify the problems in BEPV projects in Sweden based on their own experiences. Second, the informants collectively clustered the challenges based on similar orientations and effects. Third, these clusters were discussed in terms of how they affected one another. Finally, the clusters were individually ranked as “easy to handle” and

Table 2.
Details on workshops
and interviews
(replacing
workshops)

Actor group	Workshop/interview duration (minutes)	No. of participants
Architects	158	5
Client I	129	8
Client II	90	4
PV experts	105	7
Grid owners	76	7
Contractors	45	4
PV suppliers (five interviews)	190	5
Technical consultants	65	5
Electrical contractors (four interviews)	136	4
Verification workshop	120	27
Total	1114	76
Source: Author's work		

“important to handle”. The clustering and ranking of the categories served to support the discussions in the groups. They also gave a deeper understanding of the actor-related problems and a rich picture of the identified individual experiences and perspectives, transformed into qualitative collective empirical insights. In the interviews, the steps shown in [Figure 2](#) were carried out individually: the informants individually clustered their identified problems, discussed their perceptions and experiences of the clusters with the interviewers and finally ranked the clustered problems. The data from the separate interviews were merged into results for the specific actor groups (i.e. PV suppliers and electrical contractors).

Following the data collection, the data were triangulated by inviting all workshop and interview informants to a verification workshop. In this workshop, the results were clarified, and the discussions enabled a revision of the preliminary analysis. The data collection was not limited in time but lasted as long as needed. The data collection was done in Swedish, and the workshops and interviews were recorded and transcribed. The citations were translated by the author.

Analysis

The research design follows [Dubois and Gadde \(2002\)](#), who suggested that empirical observations must be conducted to understand theory and, vice versa, that theorizing should strive to explain empirical observations. In addition, the objective of any research should be to confront theory with the empirical world. The initial approach and data analysis followed an inductive approach, with continuous comparative analyses conducted to achieve an explanatory view of the studied phenomenon ([Eisenhardt, 1989](#)). During the analysis, the inductive approach developed into an abductive approach, moving towards discovering new aspects of BEPV and contributing new insights to existing theory ([Dubois and Gadde, 2014](#)) on systemic innovation in construction. As an understanding of the meaning of the studied phenomenon developed, further dimensions from the discussions emerged. Confronted by theory, the data were resorted, and the identified problems were reorganized iteratively to contribute to the theory ([Dubois and Gadde, 2002](#)).

The data were coded using the NVivo software and structured after the actor groups and the identified challenges. As a result of the data collection, a total of 68 clusters were defined. These clusters overlapped to a great extent. The 68 clusters were used to give a picture of the actors’ focus and main resulting challenges, but the informant-identified clusters were not used as final categories for this study. Rather, following the procedure of qualitative thematic analysis by [Nowell *et al.* \(2017\)](#), the cluster contents were used to generate initial codes, which resulted in a structure of 16 categories. Following the coding process in [Nowell *et al.* \(2017\)](#) enabled gaining reflective insight into the data. Secondly, the initially generated 16 categories were summarised and condensed into four theme categories, following their contents. Thirdly, these theme categories were reviewed and discussed among peer researchers involved in the data collection, and consensus regarding the themes was



Source: Author’s work

Figure 2.
Steps of the
workshops and
interviews

reached. Finally, and as a result, these representative categories were named mirroring their contents.

The findings and the results of the analysis were developed iteratively and are therefore presented jointly in the next section.

The informants identified problems linked to their perceptions of BEPV projects, and so the data collection also contained information about barriers to the processes before and after the actual implementation process. However, to keep the focus on the research question, any information regarding processes other than the implementation phase was removed.

As stated above, the nature of systemic innovation in BEPV requires an inter-organisational focus and consideration of many aspects, which differs from studying other types of innovation. Therefore, to explore similarities and build on present knowledge regarding implementation of systemic innovation in construction, a comparison was made between this study's results and barriers to systemic innovation implementation, given in the construction literature, following the analysis.

Findings and analysis

This section starts with a description of the identified barriers, organised as a result in the final categories. The barrier categories are then used to describe the systemic characteristics of BEPV in construction. Finally, the identified barrier categories are compared with barriers to systemic innovation in the literature to contribute to a finer-grained understanding of systemic innovation in construction.

Actor-identified problems

The barriers identified by the actors were divided into four representative categories, presented and described in Table 3. As stated in the section “research design and method”, barriers identified outside the implementation phase were excluded. Table 3 shows the actor-identified barriers sorted into categories, further explored in Table 4, broken down by type of informant.

Technical and material issues. As the headline signalizes, PV has not been available for long in Sweden, and therefore, this category contains technical and material issues identified

Category	Description
Technical and material issues	– Problems related to development of both PV-related technology and PV applications – Problems with material distribution
Lack of competence	– Problems related to construction actors' lack of PV-related education, training and experience
Informal institutions	– Problems related to legitimacy of PV, conceptions, and informal norms among actors – Problems related to lack of integration of PV as a discipline in construction – Problems related to lack of established work routines for integrating PV-related values and solutions into other disciplines
Formal institutions	– Problems because of incomplete or missing regulations, standards, formal codes and classifications in construction

Table 3.
Categories of actor-identified barriers

Source: Author's work

Actor group	Technical and material issues	Lack of competence	Informal institutions	Formal institutions
Architects		– Lack of appropriate project manager and architect education – Lack of knowledge of possible PV solutions and applications	– Challenges regarding perceiving PV as a building material – Lack of mutual understanding at all levels – PV supplier's lack of understanding of the construction industry	– Gaps in regulations – Problems with building permits
Clients		– Lack of technical knowledge – Lack of competent consultants – Suppliers' lack of competence and holistic overview	– Built environment is not adapted to PV – Client uncertainty about requirements for handling unforeseen issues during system operation	– Regulations perceived as short term in focus and unclear
PV experts		– Complex optimization of self-used PV electricity – Lack of knowledge of roof strength for PV projects – PV suppliers' lack of electrical competence – Lack of knowledge of integrating solar electricity in energy performance calculations	– PV lacks a given place in the design phase – Discrepancies in expectations regarding PV expert competences – Discrepancies in communication between actors during the design phase – No industry consensus about what solar radiation data to use	– Lack of special requirements regarding connection to the grid and of national regulations for using the grid – Broad uncertainty about laws and regulations – Lack of standards for solar electricity data input into energy performance calculations
Grid owners	– Grid limitations – Rapid technological development that creates uncertainty	– Lack of professional completion and connections – Grid owners' customers' lack of knowledge – Lack of own knowledge	– Grid owners engaged late in the process	– Uncertainty about subsidies and tax rules – Lack of coordinated, national rules for PV connection

(continued)

Table 4.
Barrier categories

Table 4.

Actor group	Technical and material issues	Lack of competence	Informal institutions	Formal institutions
Contractors	– Hard to find solutions to match specifications	– Deficient own knowledge	– Low impact on the design of energy systems	– Incomplete regulations and requirements linked to implementation – Incomplete standards for PV construction – Grant applications – Unclear and incomplete regulations
PV suppliers	– Lack of retailer capacity to deliver material – Unreliable material delivery	– Authorities lack knowledge – Implementation errors – Lack of customer, manager, and design competence	– Grid owners lack interest	
Technical consultants		– Lack of own knowledge of PV system design – Incomplete PV-related construction technology solutions – PV suppliers lack construction technology knowledge	– PV is not a standardized discipline in the design phase	– Diverse and unclear regulations that affect specifications
Electrical contractors	– Mounting instructions not adapted to the Swedish market – Incomplete material delivery	– Electricians and fitters lack knowledge – Designers lack knowledge	– Difficult PV work prerequisites (i.e. outdoors all year) – Grid owners lack interest – Actors given PV-related tasks outside their expertise	– Difficulties regarding regulations affecting PV – Lack of regulations, advice and instructions – Lack of instructions and standards for connecting a PV system to the building system

Source: Author's work

as affecting implementation. There is still ongoing development of both PV-related technology and new PV applications, such as mounting, façade or material integration and PV systems connected to energy storage or closely integrated into smart systems for small energy communities. The data show that the fast development and change of applications are challenging actors to keep up. For example, the grid owners found the fast development problematic since they were uncertain of the extent to which they needed to prepare and adapt their grids and connections. As of the time of data collection, they had not yet focused on connections and preparations for PV systems. PV suppliers reported incomplete or late deliveries of PV material from their retailers as a barrier to BEPV installations. They explained this as the result of the fast increase in market demand. A PV supplier expressed retailers' lack of knowledge to have implications on material delivery through the statement:

They have started working with PV without knowledge [...] but they sell it, so we get the wrong material at the wrong time. They have not learned it, and it's still a bit new. We have to let the market take its course, and in the end, it will be good too, but right now, it is too young.

Similarly, the electrical contractors claimed that the mounting instructions for the PV material were often not translated and were difficult to understand. This indicates that the retailers have not prioritized adapting the deliveries to the Swedish market due to overall high market pressure; to their frustration, this lack of adaption has affected the scheduling and quality of BEPV projects.

Lack of competence. Reportedly, there is an existing lack of PV-related competence among construction actors. PV-related knowledge exists, but there is a gap between the knowledge and its application through actors' competencies in projects. All groups experienced frustration regarding the lack of competence that pervades both their own group and other groups (also shown in the previous category). This problem was discussed regarding PV-related technology and design and was said to affect the whole implementation process. All actor groups described this as the result of a supposed lack of PV-related technical education, training and experience. The actors reported that they were uncertain about how to obtain appropriate information and solve BEPV-related problems and complained that they lacked sufficient time to prepare and gather the knowledge needed for their tasks within a project. For example, the clients perceived that they lacked PV-related competence. They reported being uncertain about what activities and competencies they needed to involve in a project when implementing PV. This uncertainty in the design phase affects the project's ensuing workflow. The clients expressed difficulties obtaining information and knowledge from other actors, as they were used to doing regarding other issues. This was expressed by a client representative:

[...] there are others who should know this better and advise me [...] I should be able to buy competence[, but there is a] lack of competent advice.

The architects experienced a prevailing lack of competence and education on PV-related issues in all construction disciplines, leading to difficulties in cooperating for solutions in the design phase. Similarly, the electrical contractors reported that actors without adequate training were given BEPV installation tasks due to the high market pressure and the resulting difficulty in finding personnel. This was stated by an electrical contractor:

It can be any constructing firm or piping company, anyone installing PV systems. All that is required to connect to the electricity grid is that you have a qualified installer, but apparently, there are people who sell such services [...] we have seen many electrical faults that we have had to fix.

The fast development of PV technology and applications in construction requires continuous competence development among actors involved in PV implementation, and awareness of this creates uncertainties in keeping up with PV development, in education, and in staying informed. This was especially reported by actors who do not have PV as their core business (i.e. clients and grid owners) and were thus limited to making extraordinary efforts to keep informed of rapid PV development. Furthermore, there was a pervasive perception that other actor groups should have higher competence than shown; for example, the electrical contractors reported that PV suppliers lacked electrical competence, illustrating a discrepancy in expectations of other actors' competence.

Architects, clients, PV experts, contractors and grid owners reported that they lacked competence in PV technology. In contrast, PV suppliers and electrical contractors did not mention their own lack of competence when identifying problems. This could be because the core business of these suppliers is PV systems. The PV suppliers tended to focus on factors affecting their business and opportunities for the market to grow rather than seeing their own PV-related competence as an issue. Rather, the PV suppliers identified others' lack of competence. As an example, one supplier claimed consultants were in the early stage of knowledge building:

It feels like they are very self-taught, no one knows enough about PV, can calculate on it or to some extent lead projects [...] it is the knowledge that is missing [...]

In line with this, the technical consultants claimed that they lacked competence in how to design PV systems but did not see this as their task; hence, they did not regard PV-related knowledge as required, so a lack of it was not a problem. Rather, the technical consultants stated that PV-specific competence should be located elsewhere, as in the case of other specific technical questions faced in construction projects. Following the technical consultants, the electrical contractors focused on implementing instructions from other actors rather than claiming that they needed to acquire new knowledge.

When actors who identified their own lack of competence as a problem (i.e. architects, clients, PV experts, grid owners and contractors) were given tasks related to PV technology, this was related to their awareness that the inclusion of PV systems would be an ongoing feature of their work, and they anticipated that their function would be highly embedded in their work in the future. Unlike other actors, who were only involved in PV implementation and not in PV operation (i.e. PV suppliers and electrical contractors), they realized that they needed a certain amount of detailed knowledge to be able to integrate PV into their work and business. The analysis shows that actors traditionally engaged in construction (i.e. architects, clients, technical consultants and electrical contractors) and grid owners realized that they had to deal with PV-related issues in construction projects for which they were not educated. They understood that they had to find work processes for this in line with their work in general and that they had to obtain PV-related knowledge to do so. In contrast, PV suppliers were brought into projects to deliver products, and they were not concerned about adapting their knowledge to the entire process.

The electrical contractors described the PV market as a young market, leading to uncertainties regarding installations, difficulties finding correct competencies, and some activities being conducted by unauthorized personnel. The electrical contractors said that problems are fixed *ad hoc* during installations, but, as in other matters, competence will grow with time.

Informal institutions. The rapid increase in both societal interest in PV and the variety of new application areas in construction have led to high market pressure. Consequently, construction actors are unprepared for the task of implementing PV, and PV actors are

moving into the construction context, which is in many ways different from their own. Two industries are thus meeting around one innovation, with different conceptions of the task. This can be explained by the fact that PV is not integrated as a discipline in construction and that there is a lack of established work routines for integrating PV-related values and solutions into construction disciplines. This is shown in this study through a mismatch of perception of informal institutions, seen as socially shared and often unwritten rules. The informal institutions affecting BEPV actors, therefore, concern the legitimacy of PV in construction, actors' different conceptions of PV, and the values and informal norms of PV.

A lack of established work routines was identified by actors who perceived that PV-related tasks were given to them in an unpredictable and *ad hoc* way in BEPV projects. Technical consultants described this as the lack of a defined or routinized way to handle PV-related tasks in the design phase. Together with architects and PV experts, technical consultants described their uncertainty about how to integrate PV into their disciplines. The architects considered the PV suppliers challenging to work with, compared with the representatives of other applications that they integrate into their design work. They explained this in terms of a prevailing lack of understanding of the opportunities to apply PV and a lack of engagement, especially within their own discipline and from clients. This indicates that PV has not yet been integrated or adapted as part of building design. The architects also said that they had difficulties obtaining PV-related information and that they needed to include PV in their work, claiming that this was because of PV suppliers' lack of engagement and cooperation in the design phase. This was expressed by an architect, claiming that there are difficulties achieving material samples from PV suppliers during the design phase:

Material samples are not on the shelf at PV suppliers. That alone is a problem. And so someone can send something that looks a certain way, but you can do it 10 other ways or 40 different ways.

PV actors have apparently not realized that they need to adapt their work to construction requirements and, in this case, to distribute samples to the actors in the design phase. During data collection, the PV suppliers did not talk about problems regarding collaborating with actors in construction, i.e. they did not mention that they operated in the construction industry. This indicated that they did not reflect on the fact that their business was within the construction industry or on what requirements might follow from this fact. This could explain why architects experienced a lack of engagement from PV suppliers.

The clients expressed frustration at the uncertainty about what activities were needed from them and others in BEPV projects. One client representative reported that since she was responsible for energy solutions in the company, she was also regrettably given PV-derived tasks unknown to her, for example, concerning energy taxes, VAT and legal aspects of energy distribution. Also, in the design phase, the PV experts expressed frustration at not having an established position or legitimacy in the design phase since they were often included only late, if at all. One PV expert expressed this as follows:

PV comes [...] too late in the planning [...] In the worst case, it comes first in the construction process, or it might be the case that it is included in the construction phase.

When included, PV experts' areas of responsibility were stated to be uncertain and undefined. They also found it challenging to be perceived as experts on a wide range of issues concerning PV and were often asked questions they could not answer. This could be because PV experts have different kinds of training and experience, ranging from environmental consultancy to electrical design. Therefore, there are no fixed prerequisites or training plans to ensure that they possess the knowledge required for an established role in

the design phase. Also, the PV experts might be expected to have knowledge of routines and work methods in construction, which they might not, in fact, have. PV experts' unestablished role and the discrepancy between their expected and actual competence also resulted from the lack of integration of PV-related tasks in construction. As seen, PV-related questions arise in unstructured and un-routinized ways and usually late in the design phase, affecting both the value of the application perceived by the involved actors and the PV system's optimal integration in the design. Lack of integration between construction and PV installation and lack of legitimacy are apparently related. Lack of integration results in lack of legitimacy, and vice versa. When PV is integrated into construction and BEPV projects reach a certain level of routinization, legitimacy will follow.

Grid owners were particularly challenged by uncertainties about how their work should be conducted regarding grid security and the quality of PV connections to the electrical grid, and they saw themselves as peripheral actors, without opportunities to influence the predetermined design when they entered a project. This shows that the BEPV installation process does not involve this actor – i.e. the grid owners do not routinely engage in construction, giving only general recommendations that construction actors can relate to and include in the design. In contrast, the electrical contractors identified grid owners as standing in the way of PV installations by setting faulty requirements for the grid connections because of their low interest in PV. This also indicates that the grid owners had not yet adapted their internal organizations to routinize the tasks connected to PV systems.

The lack of integration of PV technology into the construction industry's established disciplines or work processes can also be understood in light of the clients who claimed that the urban areas were not adapted to PV installations. They were expressing the notion that PV installations are not considered when planning urban areas and that this neglect will lead to PV module shading, resulting in faulty PV performance. This indicated that they were concerned about how to find solutions for PV installations when applied to buildings. The lack of PV integration in construction was also evidenced when the contractors said that issues concerning BEPV were far from their daily business and that they had little knowledge of the implications of PV for their construction work. Clearly, they had no routines for handling PV-related tasks in projects. Similarly, electrical contractors and PV experts claimed that they were often given tasks outside their areas of expertise and that they often conducted tasks that should not have been theirs. These actors said that there was no consensus on the definitions of the activities, competencies or responsibilities of the different involved disciplines and that they were uncertain about what knowledge they could expect from others. This insecurity regarding task boundaries and areas of responsibility led to considerable frustration.

Formal institutions. This category contains rules that are formally established and communicated through accepted and official channels. All actor groups mentioned that they experienced many problems related to regulatory uncertainties. Examples were cited regarding regulations on PV connections to the electrical grid, energy taxes affecting PV projects, economic incentives, grants, building codes, codes of conduct and building permits. The actors found these governance systems to be inappropriate and frequently changed, which caused great insecurity. The rules were also perceived as complicated, unclear, or non-existent. One PV supplier expressed this as follows:

Regulations are a part of this. There are ambiguities on how to do things. It is a state of "wild west" with something that was allowed, or nobody knew how to a few years ago [...] is not allowed today.

Generally, the construction actors affected by regulations did not have BEPV as a core competence or business. Consequently, these actor groups perceived the regulations as

complicated, and they said that they did not have the time to keep up with the latest applicable rules. They were also stressed by the perception of multiple governance systems that they had to deal with. The clients were uncertain about how rules and regulations would affect their responsibilities regarding electricity production, for example. PV experts expressed uncertainty about how their PV system designs were affected by regulations since the regulations were perceived as frequently changing. As stated in the “lack of competence” category, construction actors, especially architects, technical consultants and electrical contractors, reported that they normally found answers to questions concerning their assigned tasks in sector-specific norms but that these were incomplete for BEPV. To their frustration, they reported that they did not know where to find the required information to refer to in their specifications. Similarly, contractors specified that their usual way to find information on regulations did not apply to finding BEPV-related solutions for mounting or electrical connections. The grid owners reported that they had to adapt their business models to integrate PV systems into their grids. They reported that they were challenged by this task and that they would benefit from national standards, requirements, and processes.

Many actors identified official institutions as laggards, hindering BEPV projects. The clients and contractors identified governance systems as crucial issues in removing hindrances to BEPV installation. PV suppliers attributed the deficiencies in official institutions to lack of competence, resulting in failure to set and adapt regulations for BEPV. Also, the PV suppliers claimed that rules and regulations were frequently changed, leading to insecurity in the market. Similarly, architects reported that municipalities lacked interest in adapting building permits to support BEPV installation. PV suppliers and architects were noticeably frustrated with governmental bodies that allegedly failed to adopt sufficient rules and regulations, which hindered BEPV projects. This indicates that municipalities and national authorities have not yet caught up with the fast-growing PV market and that there are still gaps in regulations that affect BEPV.

Problems related to regulations also reflect the fact that PV is still something new in construction. PV implementation is seen as unorganized, and the associated tasks are not routinized. The present analysis reveals that PV-related information remains to be incorporated into codes, regulations and standards to a much greater extent than at the time of this study.

The systemic characteristics of photovoltaic systems installed in the built environment

This study found that expectations and perceptions regarding PV-related technology and BEPV projects differed between the actors, who were challenged in different ways. The more central a PV project was to an actor's main business, the more it was perceived as complex, and the more problems were identified. Actors involved in peripheral tasks within an implementation thus reported only a few or insignificant problems. For example, architects expressed frustration with challenges encountered when integrating PV modules into a building's architecture and function and hence perceived PV as disrupting their work due to the lack of standard applications for specific functions. In contrast, clients had a multifaceted perception of PV and a broader systemic view, experiencing that PV affected many matters that had to be managed. The PV experts talked in detail about various aspects of PV implementation concerning material connections and the building's energy performance, and they described diverse challenges regarding PV system design. However, actors traditionally outside construction (e.g. PV suppliers and grid owners) identified fewer challenges with BEPV implementation, often as individual technical questions affecting their work; for example, the grid owners focused their discussions on grid connections and

electricity quality. Nor were the contractors’ discussions detailed; instead, they saw BEPV as just another detail that comes with a project. They did not know how they could affect the process of successful BEPV implementation, but they had to adapt to a technical installation in which they depended on other actors. This discrepancy between BEPV perceptions indicates that the involved actors had to accept considerable interdependence, reinforcing the highly systemic nature of BEPV as an innovation.

Furthermore, the systemic character of BEPV implementation, with its great variety of aspects, required the involvement of many actors. As the analysis progressed, a view emerged of a great diversity of factors affected by and affecting BEPV projects. These factors, summarized in Table 5, were partly explicitly identified by the informants, but a wider range of factors emerged during the analysis. These many factors provoked many actors, who felt challenged when assigned completely new tasks because of BEPV implementation, tasks to which they had to adapt in radical ways. Interestingly, more such factors were associated with BEPV implementation than any involved actor had anticipated. The actors had apparently anticipated that BEPV implementation would be a relatively simple task in a construction project, but as shown, it was not perceived as such in practice. As BEPV projects are not integrated into construction and are not standardized, a high degree of coordination and integration is required.

Discussion

As seen from the empirical material, BEPV, viewed as a case of systemic innovation, has characteristics that, in general, are similar to but also different from those of other systemic

• Building permit • Energy tax • Economic grants • Building codes • Building energy performance • Own use and value of PV • Non-concessional grids • Grid connection • Snow loads • Wind strength and lifting forces • Roof strength • Profitability calculations • Electricity price • Inflation • Internal interest rate • Solar radiation data • Electrical certificate system • PV electricity trading	• Energy storage • Smart control • Fire safety • Rescue service operation • Electrical safety • Sustainability certification system • Roof mounting • Architecture • Building envelope • Material • Circularity • Recycling • Electricity production • Direct current • Alternating current • Shade calculation and effects • Construction inspection • Electrical inspection	• Energy strategy • Property management • Building renovation • Maintenance and servicing • Property development • VAT issues • Energy producer specificities • Energy payback time • Business models • Corporate social responsibility • Overall energy management systems
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Table 5.
Aspects of BEPV
projects

Source: Author’s work

innovations. BEPV entails a high degree of interdependencies regarding material and activity exchange, and many actors are involved, revealing BEPV to be highly systemic. Also, BEPV routines and implementation processes are neither established nor standardized and need to be set. This has been recognized in previous studies of the development process of systemic innovations (see, for example, [Lindgren and Emmitt, 2017](#)). The inapt adaption of BEPV-related standardization also contributes to the highly systemic innovative character of BEPV, which impedes implementation in project-based settings ([Taylor and Levitt, 2004](#)). BEPV standardization is needed, and the BEPV implementation process calls for adaptation of the management strategy ([Lindblad and Karrbom Gustavsson, 2021](#)). In construction, clients often assume the managerial role and would therefore need to address these challenges. When implementing a complex innovation, clients must secure resources and competencies for the task and ensure that sufficient resources are available ([Blayse and Manley, 2004](#); [Gann and Salter, 2000](#)). However, this study shows that clients lack competence in how to go through the BEPV implementation process. Clearly, to succeed with BEPV implementation, clients need technical skills to understand the extent of the innovation to be implemented and to take the risk that it might constitute ([Winch, 1998](#)). Before the implementation process is standardized, individuals' and actors' responsibilities will remain unclear ([Taylor and Levitt, 2004](#)). Hence, the clients have an essential role in handling the many interdependencies and new tasks and in adopting a project management strategy based on an understanding of challenges to establishing this implementation process and achieving standardization. With time, this task will be easier as repeated implementations lead to the building of this required specific knowledge.

The actors experienced different types of barriers related to BEPV implementation, depending on their areas of expertise, knowledge, background, type of education and training, and industry affiliation, all of which differed greatly. In addition, they were imbued with uncertainties regarding technology, encounters between two industries, and regulations. The identified discrepancies in the expectations and perceptions of BEPV and in the expectations of competence from other actors mirror what the literature states about construction actors, i.e. that they work individually and are often mostly concerned with their own interests ([Tatum, 1986](#); [Winch, 1998](#)). Clearly, BEPV-related knowledge is built in specific projects. This tacit knowledge gathered at a business level from individual BEPV projects, on its own, is, however, insufficient to support the innovation process or the sector's development ([Havenvid *et al.*, 2019](#)). Rather, to create embedded knowledge in the industry and the standardization of BEPV, new knowledge-building arrangements are required that address the lack of adequate training and education and access to knowledge pools. One example of successful knowledge building in the industry is the Swedish Energy Agency's networks for real estate owners committed to energy efficiency. In these networks, member firms strategically cooperate to assess new technologies for sustainability, increase energy efficiency and build and disseminate knowledge ([Haugbølle and Boyd, 2017](#), p. 244).

In addition to similarities to the systemic characteristics of innovation identified above, the emerging picture of BEPV implementation shows that it is a very complex task. BEPV implementation is affected by a wide variety of factors, and the involved actors are unprepared for the task's complexity, likely due to its simplistic nature at first sight, a matter that previous studies have not raised clearly. Hence, beyond the attitudinal, industrial and institutional factors identified by [Vennström and Eriksson \(2010\)](#), the BEPV case also includes actors unprepared for the tasks that implementation entails. The actors are not only unprepared for their own BEPV-related tasks, but they are also unprepared for their dependency on other actors' material deliveries and solutions. This unpredictability and the high degree of interdependence influence and affect the BEPV implementation

process. Also, the systemic characteristics of BEPV implementation entail a high degree of interdependence between actors and disciplines, the adaptation of multiple physical connections and materials, and interdependence between installations to a greater extent than merely the reorganization of communication and administrative systems (Samuelson and Björk, 2013) or the change in actors' work processes, as found, for example, in the case of multi-storey housing in timber (Lindgren and Emmitt, 2017). Consequently, to build knowledge of BEPV and other highly systemic innovation implementations, we must understand the details of the systemic innovation process.

In parallel, the radical shift in function when a building becomes an energy provider adds to the important issues to be considered when implementing this systemic innovation (Hemström *et al.*, 2017). It also raises the need to discuss the magnitude of systemic innovation to understand the extent of adaptation and interaction in the implementation process. On top of the regulatory, normative and cognitive factors shown to hinder systemic innovation implementation, all of which reinforce industrial path dependency, this study shows that the implementation of BEPV, as a systemic innovation, is hindered by a broad range and large number of factors and a high level of complexity. In addition to the factors identified by Blayse and Manley (2004) as influencing innovation, BEPV projects also greatly change the project's product – the building (Hall *et al.*, 2020). Installing PV changes a building from being merely a shelter from weather to being an active part of the energy system. Consequently, the building shifts from being perceived as only an object constructed of wood or concrete to being perceived as a system producing electricity in addition to providing space for homes and businesses. Through the possibility of installing active systems producing electricity, construction actors assume the completely new societal task of energy transition, and buildings receive new goals. This situation might imply that new roles are needed for this transition; i.e. a role connecting the building's new functions with affected instances, such as grid companies, insurance companies and banks, could ease the process.

Conclusions

The aim of this study was to explore the process of the implementation of BEPV and to improve the understanding of systemic innovation in construction. This was done by using BEPV as a case of systemic innovation, focusing on inter-organisational issues and aspects affecting a diversity of involved actors. The study identified many barriers, organized into four categories: *technical and material issues*, *lack of competence*, *informal institutions* and *formal institutions*. *Technical and material issues* relate to the fast development of PV technology and applications, with the actors showing uncertainty about what applies in their contexts. In addition, actors were affected by incomplete deliveries and incomplete instructions due to high market pressure. *Lack of competence* stems from actors' inadequate training, education and experience with BEPV, which applies to both interior and exterior construction. *Informal institutions* concern conceptions and legitimacy of PV. This category also relates to uncertainties linked to the implementation process and its lack of work routines. *Formal institutions* refer to problems deriving from incomplete standards, regulations and formal norms regarding BEPV. A key issue is that the level of technological maturity greatly influences the categories, i.e. the presence of unpredictable activities challenges the actors greatly. With increasing technological maturity, the character of the systemic set-up will likely change, for example, resulting in clearer interfaces and "knowing what to do". The study showed a great number of aspects to consider when implementing BEPV, revealing BEPV to be highly systemic.

The practical implications of this study are the showed necessity to improve technical BEPV-related competence to meet the challenges of BEPV in construction. This calls for educational plans and integration of knowledge-development measures in existing educational institutions, including specific coordination requirements and clients' strategic plans for implementation. For BEPV to contribute more to the energy transition as part of the climate responses urged by society, governments and public organizations need to develop, adapt and implement appropriate political regulations, industry norms and standards.

This study adds knowledge on systemic innovation in construction, showing the need for a finer-grained scale for systemic innovation definition. This was shown by comparing barriers previously highlighted in research on systemic innovation and with identified previously unknown BEPV-related issues, showing a gap for deeper knowledge on systemic innovation. This implies that further research is needed on the process of implementing highly systemic innovations, improving our understanding of systemic innovation implementation in construction. Through this, more specific and better-adapted strategies for BEPV implementation in construction could be developed. Furthermore, knowledge development is a significant core issue for the implementation of systemic innovations, so further studies of the knowledge dimension of BEPV implementation could build more detailed knowledge of and guidance for systemic innovation implementation. Studies using knowledge frameworks have shed light on the structure of knowledge building process (Lindgren, 2018; Slaughter, 1998) and would be suitable to develop this type of study further.

References

- Andersson, J., Hellsmark, H. and Sandén, B. (2021), "Photovoltaics in Sweden – success or failure?", *Renewable and Sustainable Energy Reviews*, Vol. 143, p. 110894.
- Blayse, A.M. and Manley, K. (2004), "Key influences on construction innovation", *Construction Innovation*, Vol. 4, pp. 143-154.
- Creswell, J.W. (2003), *Research Design*, Sage publications, Thousand Oaks, CA.
- Curtius, H.C. (2018), "The adoption of building-integrated photovoltaics: barriers and facilitators", *Renewable Energy*, Vol. 126, pp. 783-790.
- Dubois, A. and Gadde, L.-E. (2002), "Systematic combining: an abductive approach to case research", *Journal of Business Research*, Vol. 55, pp. 553-560.
- Dubois, A. and Gadde, L.-E. (2014), "Systematic combining – a decade later", *Journal of Business Research*, Vol. 67, pp. 1277-1284.
- EC (2020), "Regulation of the European parliament and of the council establishing the framework for achieving climate neutrality and amending Regulation (EU) 2018/1999", European Climate Law, Brussels.
- Eisenhardt, K.M. (1989), "Building theories from case study research", *Academy of Management Review*, Vol. 14, pp. 532-550.
- Eriksson, P.E. (2013), "Exploration and exploitation in project-based organizations: development and diffusion of knowledge at different organizational levels in construction companies", *International Journal of Project Management*, Vol. 31, pp. 333-341.
- Gann, D.M. and Salter, A.J. (2000), "Innovation in project-based, service-enhanced firms: the construction of complex products and systems", *Research Policy*, Vol. 29, pp. 955-972.
- Hall, D.M., Algiers, A. and Levitt, R.E. (2018), "Identifying the role of supply chain integration practices in the adoption of systemic innovations", *Journal of Management in Engineering*, Vol. 34, p. 4018030.

- Hall, D.M., Whyte, J.K. and Lessing, J. (2020), "Mirror-breaking strategies to enable digital manufacturing in silicon valley construction firms: a comparative case study", *Construction Management and Economics*, Vol. 38, pp. 322-339.
- Haugbølle, K. and Boyd, D. (2017), *Clients and Users in Construction: Agency, Governance and Innovation*, Taylor and Francis, New York, NY.
- Havenvid, M.I. (2015), "Competition versus interaction as a way to promote innovation in the construction industry", *IMP Journal*, Vol. 9 No. 1, pp. 46-63.
- Havenvid, M.I., Bygballe, L.E. and Håkansson, H. (2019), "Innovation among project islands: a question of handling interdependencies through bridging", in Ingemansson Havenvid, M., Linné, Å., Bygballe, L.E.H.C. (Ed.), *The Connectivity of Innovation in the Construction Industry*, Routledge, New York, NY, N.Y.
- Hedborg Bengtsson, S., Karrbom Gustavsson, T. and Eriksson, P.E. (2018), "Users' influence on inter-organizational innovation: mapping the receptive context", *Construction Innovation*, Vol. 18, pp. 488-504.
- Hemström, K., Mahapatra, K. and Gustavsson, L. (2017), "Architects' perception of the innovativeness of the Swedish construction industry", *Construction Innovation*, Vol. 17, pp. 244-260.
- IEA (2021), "Key world energy statistics 2021", iea.org: International Energy Agency.
- Jingmond, M. and Ågren, R. (2015), "Unravelling causes of defects in construction", *Construction Innovation*.
- Larsen, G.D. (2011), "Understanding the early stages of the innovation diffusion process: awareness, influence and communication networks", *Construction Management and Economics*, Vol. 29, pp. 987-1002.
- Lindahl, J., Oller Westerberg, A. and Vanky, K. (2021), "National survey report of PV power applications in Sweden 2020", Swedish Energy Agency, Stockholm, Sweden.
- Lindblad, H. and Karrbom Gustavsson, T. (2021), "Public clients ability to drive industry change: the case of implementing BIM", *Construction Management and Economics*, Vol. 39, pp. 21-35.
- Lindgren, J. (2018), *Diffusion of Systemic Innovations in the Construction Sector*, Halmstad University Press, Halmstad.
- Lindgren, J. and Emmitt, S. (2017), "Diffusion of a systemic innovation: a longitudinal case study of a Swedish multi-storey timber housebuilding system", *Construction Innovation*.
- Manley, K. (2008), "Against the odds: small firms in Australia successfully introducing new technology on construction projects", *Research Policy*, Vol. 37, pp. 1751-1764.
- Mohammed, S. and Ringseis, E. (2001), "Cognitive diversity and consensus in group decision making: the role of inputs, processes, and outcomes", *Organizational Behavior and Human Decision Processes*, Vol. 85, pp. 310-335.
- Nowell, L.S., Norris, J.M., White, D.E. and Moules, N.J. (2017), "Thematic analysis: striving to meet the trustworthiness criteria", *International Journal of Qualitative Methods*, Vol. 16, p. 1609406917733847.
- Orstavik, F. (2019), "Activity systems and innovation in project-based production: the case of construction", in Ingemansson Havenvid, M., Linné, Å., Bygballe, L.E.H.C. (Ed.), *The Connectivity of Innovation in the Construction Industry*, Routledge, New York, NY.
- Palm, A. (2015), "An emerging innovation system for deployment of building-sited solar photovoltaics in Sweden", *Environmental Innovation and Societal Transitions*, Vol. 15, pp. 140-157.
- Palm, A. (2016), "Local factors driving the diffusion of solar photovoltaics in Sweden: a case study of five municipalities in an early market", *Energy Research and Social Science*, Vol. 14, pp. 1-12.
- Palm, J. (2018), "Household installation of solar panels – motives and barriers in a 10-year perspective", *Energy Policy*, Vol. 113, pp. 1-8.
- Palmblad, L., Jacobsson, S., Sandén, B. and Hall, M. (2008), "Dynamics of the Swedish PV innovation system".

-
- Rogers, E.M. (2003), *Diffusion of Innovations*, Simon and Schuster, New York, NY.
- Rose, T., Manley, K. and Widen, K. (2019), "Do firm-level barriers to construction product innovation adoption vary according to position in the supply chain?", *Construction Innovation*, Vol. 19, pp. 212-235.
- Samuelson, O. and Björk, B.C. (2013), "Adoption processes for EDM, EDI and BIM technologies in the construction industry", *Journal of Civil Engineering and Management*, Vol. 19, pp. S172-S187.
- Shabanesfahani, A. and Tabrizi, M.R.F. (2012), "Barriers of systemic innovation to increase productivity of engineering and construction industries of the world", *IOSR J. Mech. Civ. Eng.*, Vol. 4, pp. 43-50.
- Slaughter, E.S. (1998), "Models of construction innovation", *Journal of Construction Engineering and Management*, Vol. 124, pp. 226-231.
- Tatum, C.B. (1986), "Potential mechanisms for construction innovation", *Journal of Construction Engineering and Management*, Vol. 112, pp. 178-191.
- Taylor, J. and Levitt, R. (2004), "Understanding and managing systemic innovation in project-based industries", *Innovations: Project Management Research*, pp. 83-99.
- Van Oorschot, J.A., Halman, J.I. and Hofman, E. (2021), "The adoption of green modular innovations in the Dutch housebuilding sector", *Journal of Cleaner Production*, Vol. 319, p. 128524.
- Vennström, A. and Eriksson, P.E. (2010), "Client perceived barriers to change of the construction process", *Construction Innovation*, Vol. 10, pp. 126-137.
- Winch, G. (1998), "Zephyrs of creative destruction: understanding the management of innovation in construction", *Building Research Information*, Vol. 26, pp. 268-279.
- Wong, P.S. and Cronin, L. (2019), "Drivers and anticipated outcomes of solar photovoltaic projects – the construction practitioners' perspectives", *IOP Conference Series: Materials Science and Engineering*, IOP Publishing, p. 112006.
- Yin, R.K. (2014), *Case Study Research. Design and Methods*, Sage Publications, London, Thousand Oaks.

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