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Article

Successful Zero Emission Pilot Buildings – From Building Process to End-User Evaluation

Received: date; Accepted: date; Published: date

Abstract: What characterizes building processes, including hand-over and early use, that result in successful zero emission buildings? What measures should be taken to meet the requirements of clients, executing parties and users? This paper presents findings from four Norwegian pilot projects, based on interviews with 35 clients, executing parties and users. The case studies reveal that a conscious choice of approach to the transition from the design and construction of the building, to its use and operation, can increase the likelihood of completing successful buildings and generating positive user evaluations. Identified success criteria include continuity in project ownership, involvement of end-users at the early stages of planning and design, and commitment by participants involved in design and construction to contribute with improvements in the early use phase. As part of the process from high energy efficiency ambitions to good zero emission buildings, this paper recommends a close collaboration between the client, executing parties and users, and a shared understanding of, and commitment to, the projects' goals. A modification of the traditional building process-model of programming, design, construction and operation is proposed, introducing an additional phase with greater focus on hand-over and early use.

Keywords: Building process, early use phase, zero emission buildings, energy efficiency, user satisfaction, collaboration

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1. Introduction

The EU Energy Performance Building Directive [1] forces member countries to incorporate nearly zero energy requirements (nZEB) for all new buildings in their domestic building codes by 2020. Some of the solutions needed to create zero energy buildings are based on well-known, cost-effective technologies, such as the increased use of conventional insulation, commonly presented as one of the most easily accessible measures for mitigating climate change [2]. However, to create Zero Emission buildings (ZEB definition by Fufa et al. [3]) that balance all CO_2 emissions related to their construction, operation, and demolition with on-site renewable energy production during the operation phase, is a considerable challenge to the construction sector. Many individual solutions are new and untested and, as in every high-performance building, a robust and optimal interplay of the various factors affecting a building's energy performance is necessary in order to achieve ambitious goals. The attribute "zero emission" can strictly speaking only be applied to a building that has been demolished. Only at the end of the building's life can we look back and confirm that it has lived up to its potential [3]. The increasing importance of actual performance while in use, directs our attention to the use phase and its links to design goals. In this article, we investigate the transition from the design and construction of the building, to its use and operation, and discuss if connecting these phases better can increase the likelihood of completing successful buildings and generating positive user evaluations.

During the last twenty years, several societal, economic and technological trends and challenges have changed the planning, design and construction of buildings. Climate change and energy scarcity represent societal challenges that have motivated both the public authorities and the construction industry to think in new ways and produce new solutions. How to implement innovative approached and definitions such as zero energy (nZEB) or zero emission buildings (ZEB) in design and construction processes is a challenge that the building industry must approach. Mlecnik [4] points out the vital need to understand the barriers and drivers linked to the aim of establishing energy efficient buildings such as passive house and nZEB buildings as a European standard. The construction industry is dominated by small- and medium-sized stakeholders and it is difficult to disseminate innovation and knowledge to all segments within the construction industry. Knowledge about how innovation processes in the industry from early development to general application can be supported, is essential. For this reason, we need *"to understand better the experiences of enterprises that have adopted innovations in highly energy-efficient construction, as well as the opportunities and barriers they encountered"* [4] (p.120).

Kivimaa & Martiskainen [5] state that innovations in the building sector require network building, gaining support for the emergence of innovations, as well as disrupting the practices of the existing building regime. According to Bygballe & Ingemansson [6], innovation in the construction industry only happens when companies introduce new activities or carry out existing activities in a new way. This involves changes in procedures, application of new combinations of products, processes, materials, organisational structures and new markets. Blayse & Manley [7] identified major factors that drive or hinder innovation in the construction industry mainly in the UK, US and Australia. Among these factors, they name clients and manufacturers. Clients have a decisive role in enhancing innovation, and those in possession of high levels technical expertise and experience are more likely than others to promote innovative approaches and solutions. *"The key role of clients in promoting construction innovation is one of the most striking themes running through the literature"* [7] (p.4). Also, Kulatunga et al. [8] state that the client's role in terms of being a team player, promoting respect for people, and in knowledge and information dissemination, are found to promote innovation in construction processes. Manufacturers also have a key role because they provide components and products that are selected by clients, contractors and consultants. Blayse & Manley [7] also discuss that the retention of traditional management approaches may hinder change; procurement systems and regulations/standards, respectively. Aspects such as knowledge flow, interaction, the firm`s and the employees' attitudes and contributions towards innovation, and communication are important elements of innovative processes. These can be difficult to maintain in situations where relations between different stakeholders in a building project are vague and diffuse. Pulkka & Junnila [9] describe the importance of networks or "ecosystems" in which participants collaborate to create value that would not be possible for a single individual acting alone. Moen & Moland [10] analysed data from innovative building projects. They introduced a checklist of six elements that an initiator of change should consider as a basis for succeeding with innovative projects: 1. The purpose, need and legitimacy of the change. 2. Specific goals. 3. Commitment and ownership. 4. Collaboration and involvement. 5. Resources. 6. Follow-up.

If we anticipate that all these innovation success criteria are followed as part of the construction of a zero-emission building, would the success of the building during its lifetime be guaranteed? A building's success depends partly on the achievement of defined environmental goals, however in the authors` opinion it is only a success if the users value it and are satisfied. Value in building processes is only created when needs are fulfilled, and strategic goals are achieved. This includes the perspective of owner and corporate strategy, as well as the users` [11]. In this context, we stress the importance of combining research into innovation linked to zero emission buildings with a focus on the use phase after completion of a building.

1.1. Successful energy-efficient buildings from the user`s perspective

It is widely acknowledged and documented that building energy performance is different from predicted performance [12-16]. User behaviour is at least as important as the efficiency of the technology when explaining energy consumption in buildings [17]. Moreover, studies invoke the use of buildings, and the significance of the roles and active involvement of building operators and facility managers to explain these gaps [18]. Thomsen et al. [19] studied the interaction between buildings and their users, and specifically how the users' use of interfaces and knowledge, and their commitment, influences their awareness of energy consumption levels. In general, users were pleased with living in a new energy-efficient building. However, many reported that they had received too little information about operational systems, or that the systems did not function as they expected them to. Users tend to be much less satisfied when they cannot understand how building technologies work or how they can control them [20-22]. Perceived personal control and enough information about operation and use are crucial if a user is to have an overall positive experience of the building and its technologies [19]. The hand-over phase is crucial to the user`s understanding of how to operate a building.

There are various approaches to improving understanding among users, and to managing hand-over and the early use of energy efficient buildings. Thomsen & Hauge [23] found that communication between construction and other professionals and occupants influences how occupants adapt to the technical systems they encounter in their new housing environment. Occupants requested more user-friendly information on moving into their new home. The hand-over phase and the period immediately afterwards are critical for an occupant's ability to adapt to a building's performance. Owen & Mitchell [24] stated that, currently, the role of technology installers in influencing energy consumption behaviour is an overlooked opportunity. The need for specific user instructions about the use, operation, and maintenance of heating and ventilation systems was also stressed by Mlecnik [4]. A greater focus on motivating professionals to transfer knowledge and increase occupants' awareness of the operation of a building may contribute to a better correspondence between expectations, behaviour and consumption in the long term – thus to a successful building from the user`s perspective.

In 2005, May & Boardass [25] developed the "Soft Landings" framework with the objective of smoothing the transition between the design and construction and operation phases. The idea of Soft Landings has evolved from the parallel observations that on the one hand, the building industry seemed to be incapable of learning from the buildings they produced, while on the other, building owners commonly experienced that their new building did not meet their operational expectations. The “Soft Landings” framework proposes a continuous process that provides additional support as early as during the procurement process and which continues for a period agreed upon after completion of the project [25]. In the UK the Soft Landings procedure is operationalized and promoted by the BSRIA (www.bsria.co.uk) and up-dated continuously. Another approach is the so-called commissioning or re-commissioning of energy efficient buildings, which focus on the optimization of existing building equipment systems and behavioural changes after hand-over [26]. The commissioning of new buildings aims to ensure that a building delivers and exceeds performance indicators and energy use promised during the design phase. Commissioning implies the identification of deficiencies and the implementation of relevant interventions. Commissioning is said to be the single most cost-effective strategy for reducing energy, costs and greenhouse gas emissions in buildings today [26]. Commissioning for optimal energy performance is a key process designed to close the gap between “as-designed” and “as-operating” energy consumption in new buildings. However, due to time limits and budgetary constraints, the scope of commissioning is often limited. The importance of post-occupancy commissioning in delivering effective energy and environmental performance in new buildings is now widely recognized through practices such as “Soft Landings” [27].

2. Materials and Methods

2.1. Zero Emission Buildings in Norway

While the discussion of how to interpret the term “nearly zero energy” in Norway and many EU member states continues [28], the leading Norwegian building research centres have developed a set of related standards for buildings that go beyond “nearly zero energy” by focusing on CO_2 emissions related to buildings during their entire life cycles (ZEB.no[1]). In 2017 after eight years of operation the ZEB Centre has developed its definitions based on basic research and practical application in 9 pilot buildings. The research encompasses the use of new materials, construction methods, envelope technologies, as well as energy supply systems and services. Research on use and operation complemented these activities.[2] A zero emission building, as defined by the ZEB Centre, produces enough renewable energy to compensate for the building's greenhouse gas emissions over its life

1 The Research Council of Norway assigned the Faculty of Architecture and Fine Art at NTNU to host one of eight new Norwegian centres for Environmentally-Friendly Energy Research (FME). ZEB, which was launched in 2008 and terminated in January 2017, was dedicated to research, innovation, and implementation within the field of energy-efficient, zero emission buildings. The main objective was to develop competitive products and solutions for existing and new buildings that promote market penetration of buildings with zero greenhouse-gas emissions in terms of design, construction, operation, and demolition. Research at ZEB encompassed residential, commercial, and public buildings. See also: www.zeb.no.

2 A complete publication database is available at http://zeb.no/index.php/en/publications.

span. The definition of "ZEB ambition" is differentiated depending on how many phases of a building's lifespan are included in the evaluation (see definitions in the text box). The ZEB definition is not a binding technical standard to be followed, it is a voluntary choice of the stakeholders to pursue this ambition. In this paper, we argument that a zero emission building is as successful when two conditions are given: firstly, the ZEB ambition is achieved and, secondly, when *the users are satisfied with the process and the outcome.*

Text box: The main levels of "ZEB ambition" are as follows [29], [3]:

- ZEB-O÷EQ: Emissions related to all energy use in operation "O", except energy use for equipment/appliances "÷EQ", shall be compensated for by using on-site renewable energy generation.
- ZEB-O: Emissions related to all operational energy use "O" shall be compensated for by using on-site renewable energy generation.
- ZEB-OM: Emissions related to all operational energy use "O" and embodied emissions from materials "M" shall be compensated for by using on-site renewable energy generation.
- ZEB-COM: Emissions related to construction "C", all operational energy use "O" and embodied emissions from materials "M" shall be compensated for by using on-site

2.2. Research aims and analysis frameworks

In the ZEB pilot studies, project participants and their organizations had to follow an innovative, theoretical definition. We hypothesised that this would trigger a need to change mindsets, working methods, contractual issues, roles and more. This paper addresses the following questions, related to the pilot buildings:

- What characterizes the building processes in the pilot buildings, that result in successful zero emission buildings?
- How is the hand-over phase organised and what is the significance for user satisfaction in the cases studied?
- To what extend are the findings applicable to other building processes with comparable high ambitions?

The results on the process will be structured according to the innovation success checklist introduced earlier, by Moen & Moland [10]. The results on the user perspective will be analysed referring to the Domestication theory. Domestication theory is a multidisciplinary social science approach that underlines the importance of interaction between society at large (policy, tools and contracts), technology and material conditions, user needs, motivation and day-to-day routines [30-32]. In order to domesticate technology or sustainable buildings, people need to negotiate the meanings and practices linked to these issues in a dynamic, interactive manner. The technology must make sense within the users' own cultural framework [33]. This perspective helps us to comprehend how knowledge and information are selected, transformed and put to day-to-day use. Domestication strategies take place in three domains: 1) the practical: actual use, 2) the symbolic: people`s interpretation, and 3) the cognitive: learning and familiarizing [34].

2.3. Method

2.3.1. Case studies

We have carried out qualitative case studies of four real-life ZEB pilot projects. Case studies provide an in-depth analysis of a situation focusing on context, process and relational factors [35-37]. Qualitative case study research can be generalized through comparing case study contexts to similar situations, we therefore believe that many of the findings are relevant also to other ambitious building processes [36].

The method was chosen to obtain an in-depth knowledge of the building process for the selected zero emission pilot buildings, as well as the early use phase for three of them (the fourth project was not yet completed during our study). Our aim was to describe and understand the barriers and opportunities linked to the processes leading to the completion of zero emission pilot buildings.

Table 1 provides a brief overview of the four case study buildings.

Table 1. Data overview of the four case study buildings in Norway.

	Skarpnes residential development	**Visund Haakonsvern**	**Powerhouse Kjørbo**	**Heimdal High School**
Photo				
Location	Arendal, Norway	Bergen, Norway	Sandvika, Norway	Trondheim, Norway
Type of project	5 single-family residential buildings	Office building	Office building, renovation	High School and sports hall
Heated floor area	154.2 m^2/house	2,031 m^2	5,000 m^2	26,300 m^2
Year of construction	2014-2015	2015	Original: 1980 Renovation: 2014	2016-2017
Level of ambition	ZEB-O	ZEB-O ÷ EQ	ZEB-O ÷ EQ	ZEB-O+20%M
Project delivery	Design-build	Design-build	Design-build	Design-build with pre-qualification and partnership contract
Phase of introduction of the zero-emission goals	Strategic definition phase	Concept design: three alternatives (TEK10, energy-level A, zero emission). Detailed design and	Concept design	Phase one of the pre-qualification process.

		construction: the ZEB alternative.		

Heimdal High school was the last building to be completed and opened its doors in August 2018. Only one of the pilot projects was completed as scheduled (Kjørbo). Requirements such as unknown ZEB-solutions, and the strong focus on materials, required more time than was estimated in most cases.

2.3.2. Interviews

We conducted qualitative and semi-structured interviews, either with individuals or as group interviews of 5-8 persons per case study. Interviewees were selected from among key personnel involved in the planning and construction process. The objective was to shed light on the process from the different perspectives of parties such as project owner, architect, contractor, consultants and users. Building users were interviewed at home (Skapnes), by telephone (Kjørbo), or in their offices (Visund, Kjørbo). At the time of the study, Heimdal High school was not completed. Since the stakeholders were participants at the ZEB Centre, the professional interview partners were recruited without difficulty. The interviews were conducted as far as possible as informal conversations. An interview guide with open questions was employed (e.g. "how would you describe…"). The topics covered during the interviews were: 1) person/role in the building process, 2) description of the building, 3) ambitions and aims, 4) organization and collaboration, 5) learning and knowledge, 6) costs, 7) societal context – the municipality's role, and 8) evaluation of solutions. The users were contacted by email. The following main topics were covered in face-to-face interviews with the users: 1) person, prior knowledge of ZEBs, 2) expectations, 3) evaluation of the buildings' interior climate, technical solutions, architectural solutions, and 4) comparison with former house or workplace. Table 2 provides an overview of the sources of empirical data.

Table 2. Overview of interviewees per case study project.

	Skarpnes residential development	**Visund Haakonsvern**	**Powerhouse Kjørbo**	**Heimdal High School**
No. of interviewees	6 individual interviews	8 interviewees (2 individual and 3 group interviews)	17 interviews (7 interviews with 8 interviewees in phase 1. An additional 10 interviews)	4 interviewees (2 individual interviews, 1 group interview)
Role of interviewees	Project manager and contractor, architect, consultant, users	Project managers (client), user representative, managers and operating staff in design team and contractor.	Project owner, project manager, contractor, consultants, architect, tenant, administration staff,	Project owner representatives, architect, consultant and contractor representative

			facilities manager, executive officers.	
Time of interview	October 2015. 10 months after hand-over	April-May 2016. 4-5 months after hand-over. Supplemented in October 2016.	Autumn 2014 and Spring 2015, 8 and 10 months after hand-over. The interviews were conducted by Throndsen et al. (2016)	April 2016. Yet to be handed over.

Websites, technical reports, and e-mail correspondence containing information about the buildings were used as background data. The interviews were recorded and transcribed, and their content coded according to topics that emerged in the text. The authors of this paper come from different disciplines (environmental psychology, architecture and interdisciplinary cultural studies), and this diversity of perspectives was especially valuable during meetings where coding and findings were discussed.

NSD, the Norwegian Centre for Research Data was notified and granted the data collection (www.nsd.no).

3. Results and discussion

Firstly, we present the measures undertaken by the client and the executing parties in order to succeed with their ZEB ambitions in relation to design and construction. Secondly, we look at the hand-over and the users' evaluation of the early use stage. Finally, we discuss measures to increase user acceptance and satisfaction.

3.1. ZEB as a development project within a building project

The four pilot projects address various levels of ZEB ambitions, and represent different building typologies, scales, project organizations and procurement forms (Table 1 and 2). However, the projects share one characteristic – all participants are attempting to achieve something not done before. Compared to a "traditional" building project, success in achieving ZEB ambitions during the pilots requires a will, as well as the means, to manage and accept resulting change, risk and innovation needs. This exercise can be regarded as a project in itself – or as a "development project within the building project". In the following, we will discuss the case study findings in the light of the six factors regarded as crucial to the successful implementation of change [10], [38-39].

3.1.1. The purpose, need and legitimacy of the change

During all four pilot projects, both clients and executing parties seemed to have a shared an understanding of the purpose and need for ZEB. Participants recognised an opportunity to learn and obtain new knowledge, and that this would be very useful for the environment and as well their own careers or corporate competitiveness.

This is an ambitious project but, unfortunately, such projects seldom crop up here in Bergen. And it's a nice project to put on a CV. (Executing party, Visund)

Several interviewees in the pilot projects emphasized their personal commitment to environmental issues, which gave them additional motivation to do their best to achieve the ZEB ambitions. They were happy about the opportunity to learn and develop new knowledge, and saw positive effects on their careers, their company's competitiveness, and the ability to acquire, design and construct similar projects. Blayse & Manley [7] also emphasize the significance of corporate culture and employees' attitudes to the project as a driver of innovation.

3.1.2. Specific goals

The ZEB definition acted as a guide to overall levels. All projects involved selection of a ZEB goal, which was placed one step higher on the ambition ladder in relation to the participants' experience and knowledge. The ZEB Centre played a key role in pushing ambition levels higher, and financial support from Norwegian Enova[3] was crucial to goal achievement. Process leaders had all the way to balance energy efficiency goals with those related to aspects such as functionality, user comfort, and costs. This created challenges, and at times negotiation was required between the goals. The project teams handled this differently. One project (Skarpnes) modified its ZEB goals, while others (Heimdal, Powerhouse Kjørbo) attempted to unify seemingly conflicting parameters. The Visund project prioritized the ZEB goals before other aspects, accepting potentially negative outcomes elsewhere (Visund).

We never thought that we would get so far with this project. We thought that we would go for energy class A (...), but then we changed our minds to surpass it to ZEB. (Executing party, Visund)

Change of parameters throughout the process put ambitions under pressure:

Two aspects challenged our ZEB ambitions at Heimdal High school: the choice of ventilation system and the clients` demand to increase the size of the sports hall. We experienced difficulties finding good solutions to address the energy aims. (Executing party, Heimdal)

Stakeholders shared an understanding of where they were headed. However, the path had to be defined and re-defined while the projects were underway. The importance of shared goals and logics are also pointed out as important success criteria by [40], [9].

3.1.3. Commitment and ownership

A highly committed client represented the "carrier" of ambitions linked to all projects. The findings strengthen other research implications on the major significance of client dedication and motivation [7-8]. The ZEB goals constituted an element of the assignment for the executing parties. All clients and several of the executing parties are partners in the ZEB Centre. This indicates a great interest in the concept. The commitment of the executing parties was regarded as crucial for succeeding and was stimulated in different ways:

[3] Enova is owned by the Norwegian Ministry of Climate and Environment and supports initiatives that contribute to reduced GHG emissions. www.enova.no

- In terms of public visibility: "*At some point in time, in approaching the mass media, the client had committed itself to succeed. The project manager repeatedly pointed out that we have put our heads on the block and committed ourselves to deliver this project."* (Executing party, Visund)
- In terms of competition and inclusive communication: "*We went through the ambitions in advance, and the building design manager held an engaging session when we started. He explained that here we had the possibility to create something entirely new, something never done before in Bergen. I believe that lit a spark."* (Executing party, Visund)
- In terms of the early introduction of ambitions. The clients had time to promote a sense of ownership among the executing parties before they advanced too far with the design process.
- In terms of the choice of procurement model. In the Heimdal project, the parties signed an EPC (energy performance contract). This mean that the contractor is responsible for operating the technical facilities within energy targets for the first five years. In the Visund project, the client had applied a similar principle: *"First measurements indicate that we will achieve the energy aim. This is reassuring. The contract allows a deviation of 20% on delivered energy, which is marginal in such a small project. Some call it a carrot, I call it a stick."* (Executing party, Visund)
- In terms of a shared commitment to the end-product: *"There is a well-known story about two masons who are asked what they are doing: one of them says he's laying bricks, and the other says 'I'm building a cathedral'. And they're doing the same job, right? And there's something about that – the fact that we're here building a Powerhouse that has made everyone focus on building a Powerhouse."* (Executing party/occupant, Powerhouse Kjørbo).

3.1.4. Collaboration and involvement

In all four projects, there was a focus on promoting well-working and interdisciplinary collaboration as key enablers for ZEB construction. The projects used different procurements approaches and delivery methods, based primarily on previous experience or a perception of what would be the right choice given the higher levels of uncertainty compared with "traditional" projects. The pilots indicate that there is no unique procurement approach, contract or execution model for a ZEB project, provided that such formal procedures and contracts do not in themselves hinder communication and collaboration between the parties. In all projects, the participants highlighted several informal factors as being crucial to collaboration. These included trust, openness, good leadership, good relations and chemistry between people. These factors have also been pointed out by Pulkka et al. [40] and Pulkka & Junnila [9]. Thus, effective formal procedures may not be adequate if no basic trust or willingness to collaborate exist between the parties. Another crucial aspect that emerged from the pilots is the importance of involving construction professionals (builders and site workers) in the development and design processes.

> *I have never been part of a project where there has been such good chemistry and collaboration between the parties. (...) People and chemistry play an important role.* (Client, Visund)

3.1.5. Follow-up

At Visund and Kjørbo, all interviewees emphasized the value of evaluating the selected energy solutions after hand-over. They regarded it as very useful to have the opportunity to see how the building designs functioned. In the Heimdal case, the client together with the execution party will also start to measure and evaluate the operation and use of the building for the following 5 years. One of the interviewees pointed out the substantial risks linked to building is solutions that had not been tested before and there is a need for evaluation and learning.

3.2. User satisfaction and domestication process in three of the case projects

3.2.1. Practical domestication

In general, the practical domestication [41-42] of the Skarpnes homes has been quite satisfactory. After overcoming initial challenges, residents have accepted the technology and the building into their daily routines, and express satisfaction. In retrospect, residents requested more user-friendly information about technical aspects such as the PV, heating and ventilation systems. Energy consumption data from the first-year show that residents consumed more energy in total than estimated in prior simulations, as well as more energy for heating. The PV system works well and produces more energy than was estimated [43].

Practical domestication in the first phase at Visund has not been optimal. Users struggled with indoor temperature regulation, light and sun shading. Following hand-over, the contractor was responsible for monitoring the technical systems together with the client and ZEB researchers. This group uses feedback from users to adjust and calibrate the technical systems. Such measures have the potential to improve conditions. It takes time for users to get accustomed to a new building, and it takes time to adjust the building to user feedback. Domestication failures may be attributed to symbolic and cognitive issues.

At the Kjørbo office building, a team comprising representatives of the tenant, the building owner and relevant contractors was appointed to assume responsibility for the start-up period. Eight months after moving into the new building, the team received several complaints from employees regarding building conditions. Most of the addressed comfort issues was linked to the lighting system, slight temperature fluctuations experienced as a slight chill on ground floor level, and acoustic quality in landscape areas.

3.2.2. Symbolic domestication

Symbolic aspects of technology and buildings influence user satisfaction. Users understand the zero-emission concept in ways that enable them to make sense of these issues in terms of their identity and self-presentation [41-42]. At Skarpnes, with one exception, the zero-emission concept was not the main reason why users bought their homes, although all users were pleased about the focus on the environment. The homes and technical systems functioned well once initial uncertainties were overcome. In general, users expressed a positive attitude. However, as is the case for most people, they maintained a "sustainability account" – balancing input and output. If they feel they are energy efficient in one aspect of life, they also feel they can consume more energy or be less environmentally friendly in other aspects [41].
At Visund, employees felt that their concerns during the initial planning phase had been overlooked and further influenced the users' experience of the building and its technology. No users were invited to the ZEB-workshops and they were thus not involved in the further development of measures and

systems. It is possible that they had no interest in the technical systems, but things might have been different if explanations had been provided as to how the systems would affect them. The user representative stated:

> *We were only informed when things began to take shape. (...) We have not been involved in this aspect at all. (...)The main concern of our departments is that we get the offices we need, that we get the systems we need and specific solutions. It has not been important for us that the elevator saves energy by going up and down, and such things.* (User, Visund).

When asked about awareness among employees about working in a zero-emission office building, the representative stated:

> *Yes, I think some of them are. Now I'm not speaking for others, but I think most of them do not have any relation to it (the environmental aspects of the building). People are more like "I just want to have an office." (...) I think people have a more practical attitude towards the building. Of course, some think the solutions are exciting. But it does little good when the solutions chosen do not work. I am talking about lighting in particular. (...) We must accept that it takes some time to get used to the building.* (User, Visund)

At Visund, user evaluation seems to be coloured by limited overall involvement in the planning process. More extensive user participation may have resulted in a stronger sense of ownership in the ZEB concept, and greater tolerance of failures during the running-in phase [22].
At Kjørbo, the occupants employed by the consulting company, which was also involved in the design and construction of the building were highly involved and expressed a high level of symbolic sense of ownership in the building and its ambition. They found it exciting to work in a building with a high level of technical sophistication. This was supported by the reception to the interior design, which was acclaimed for its 'premium feel'.

3.2.3. Cognitive domestication

Knowledge and understanding are crucial factors in determining a sense of comfort in energy efficient buildings. Users express lower levels of satisfaction when they cannot comprehend how things function, or are unable to regulate working temperatures and ventilation [21-22], [44]. Moreover, user participation and identification with the building (symbolic domestication) influence cognitive understanding and users' acceptance of challenges during the adjustment phases.
Residents at Skarpnes received ten minutes of instruction in the technical systems when they took possession of their homes. This resulted in feelings of uncertainty about the technology and its potential. They tested different settings, received help from providers, and finally felt that they achieved control. Overall, they were satisfied with the options and the results, saying that would have preferred more information at the start as to how to operate the heating, ventilation and PV systems. In general, the zero emission building concept was not adequately communicated to users by the executing parties. One interviewee from an executing party at Skarpnes stated

> *I think residents should have received better information early in the process. It appears that they were hesitant about the technical solutions.* (Executing party, Skarpnes)

At Visund, the move to an office building with new technical solutions was experienced as a frustrating process at cognitive level. Users reported that as individuals they had no control over lighting systems, temperature or sun shading. According to the executive party, this influences effective control of the building's energy consumption.

> *The users have experienced a move from a 1963 building to a new building with a different design. Things are getting better, and you get used to it. When one moves into one's own new house, it takes a while before everything is in place. We have to accept this. But it should not be like this in three years' time.* (User, Visund)

As previous research shows, a user's perception of individual control over his or her environment increases satisfaction in the case of energy efficient buildings [19], [45]. This may explain why the home-owners at Skarpnes express satisfaction with the buildings once they have learned how to operate the technical systems. If the systems had failed, learning in how to operate the systems would have been a much more critical factor. The limited information and training provided to residents at Skarpnes would probably have impacted negatively on their evaluations of the buildings if the technical systems had functioned inadequately. Lack of individual control over lighting, heating, and ventilation systems is common in new office buildings such as Visund. This lack of control does not become critical prior to system failure, at which point limited cognitive domestication affects users' evaluation of the building. At Kjørbo, the start-up team responded to the complaints they received and perceived, and resolved them. In general, however, the occupants of this building, who were employed by the consulting company, possessed the highest degree of technical expertise among users in the four projects described, and had a good grasp of the building and its inner workings. The process of commissioning, with its focus on system functionality and how this is understood by users [26], would probably have increased the success levels of all the buildings in the four cases.

3.3. The significance of hand-over for user satisfaction and thus for the success of zero-emission buildings

Did the participants involved in the four pilot projects succeed in designing and constructing nearly or fully zero emission buildings? In a way, they did. However, this has not been achieved without committing "something extra" to the process that boosted progress in the projects towards achievement of the agreed ZEB goals. When we examine the design and construction process, we see that the conscious focus on formal and informal implementation of the goals played an important role during the process. All four pilot projects scored high for each of the factors applied as structure for analysis [10]. We can regard these elements as characteristic of successful ZEB processes.

However, when we examine the user perspective, the success of the buildings is not always obvious. Research findings indicate that users' evaluations of a building depend on domestication at various levels [34], [42]. The energy profile is not the user's primary motivation for living or working in a zero-emission building, and users may thus not always behave as the energy concept planned such as exemplified at Skarpnes. At Visund, employees were more concerned about workspace solutions, and less about the environmental aspects of the building. This seeming lack of interest may be explained by the lack of involvement. *User involvement already in the planning process might have promoted greater levels of commitment, stronger identification with the green building concept, and a better understanding of the environmental aspects of the building.* However, measures implemented by the client and contractor after hand-over, such as calibration and better adjustment of technical systems in response to user feedback, have been perceived as positive, in line with Mills` [26] statement on commissioning. At Kjørbo, the building presents itself as an example of the skilful weaving together of a web comprising the occupants, components and architecture. The results clearly demonstrate the importance of *symbolic (identification) and cognitive (learning) domestication* as the basis for a positive evaluation of a building. The involvement of users during the building process, combined with a focus on learning and training linked to the use of technical systems, is crucial.

Our findings show that hand-over of a building from the executing project organization to the owners and users is a *critical milestone* in the process of achieving successful zero emission buildings. The pilot projects have approached this milestone in different ways, summarized below:

- Skarpnes: a traditional approach. The hand-over procedure failed to adapt to the innovative solutions applied in the project.
- Visund: contractor commitment to follow up system functionality after handover (in collaboration with the client), enabled necessary adjustments and calibrations to be made in response to energy efficiency goals and user evaluations. However, users were not involved in the development of ZEB concepts during the building process.
- Kjørbo: like Visund in terms of process and outcome, except that a group of users were directly involved in building design and construction (as technical consultants), which resulted in optimal knowledge flow across the design, construction and occupancy phases.
- Heimdal: this project has planned a one-year follow-up between client and contractor. After that, the contractor guarantees for the energy goal`s through 5 years` Energy Performance Contract (EPC).

Careful planning of the hand-over process appears to be a prerequisite for achieving successful zero emission buildings and positive user evaluations. Instead of adopting an approach that causes disruption in continuity and ownership (Figure 1), hand-over should be carried out in the form comparable to a "soft landing" [46] (Figure 2).

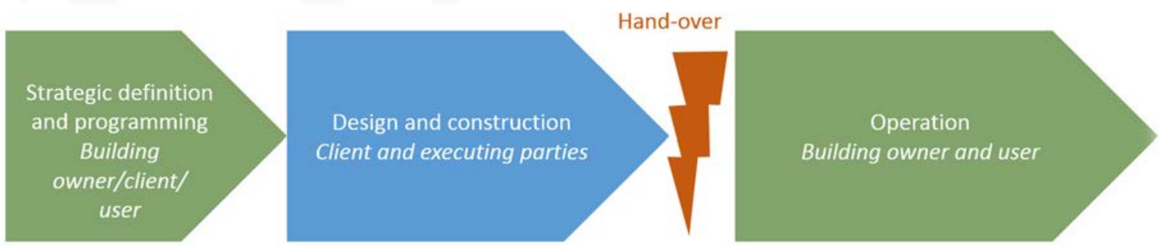

Figure 1. *Illustration of a traditional hand-over process that causes disruption between the design and construction, and operation, phases.*

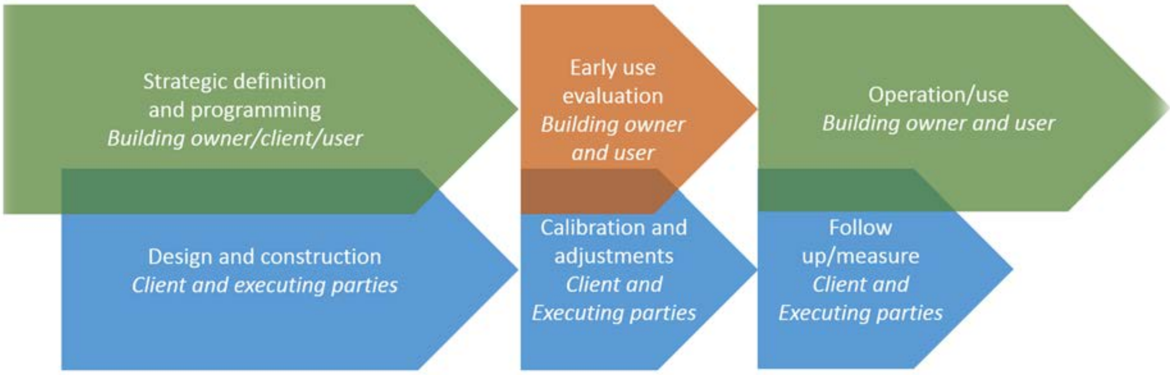

Figure 2. *A proposed modification of the traditional building process model, incorporating programming, design and construction, and operation. This involves an additional phase that focuses on hand-over and early use. The introduction of a domestication phase that "closes the gap" in the traditional approach, combined with continuous collaboration between the client, users and executing parties throughout the entire building process.*

Instead of thinking of the hand-over as a disruptive process by which new stakeholders simply take over the building, hand-over should be part of a continuum by which the executing parties supervise operation of the building until the time at which managers and users have adopted behaviours that are adapted to their new surroundings. This especially important in the case of innovative buildings where technology and architecture may differ from that which managers, office employees or home residents are used to [14].

3.4. Discussion about generalization and the limitations of the study

The case study approach adopted in this study was limited to pilot buildings carried out in Norway and the context of the Norwegian construction sector must be considered during comparisons with other countries. Moreover, all projects received support from the ZEB Centre, and do not fully reflect standard commercial practices. The special nature of this project may imply that greater resources will be required to meet the needs that such projects will generate in the standard commercial arena. The additional resources supplied to these pilot research projects will not be available to projects under normal commercial conditions. All interviewees were aware of the ambitious goals set out by the ZEB Centre. These partners were organisations with resources that are unrepresentative of the small-scale stakeholders that characterise the construction industry in most countries. However, it is common for innovation in these types of companies to occur in partnership with researchers, funded by the public authorities.

Furthermore, the users of the pilot buildings, the office workers, and the residents of the new zero-emission housing are all "real-life" users, who are indifferent to the fact that their building has been constructed as part of a research project. In particular, the findings from the use and hand-over phase is thus closely similar to standard commercial practice, and highly applicable to other cases.

In our concluding question, we asked, are the main findings applicable to other ambitious construction processes? The definition of Zero Emission Buildings is specific to Norway, nonetheless we argue that the findings are partly transferable to building processes in comparable contexts, where related goals are pursued, e.g. zero energy / nZEB, or zero carbon buildings. However, local traditions, processes, laws and regulations in different countries must be considered. We also argue that the results are relevant to the theoretical discussion on innovation in the construction sector. The findings show, and as [7] and [38] also state, the client's commitment is a major drive or hinder to innovation. However, the reviewed literature on innovation in the construction sector places little emphasis on the user`s role during the process, hand-over and operation. Lack of focus on user and use phase can be a major hinder to the success of an innovative building concept.

4. Conclusions

A conscious choice in approaching the transition from the design and construction of a building, to its use and operation, can increase the chances of achieving a successful building and positive user evaluations. Our research offers some practical measures that are important to all stakeholders in the building process. The following recommendations are of special significance in projects where clients, executing parties and users are being challenged by new and innovative solutions and processes linked to the zero-emission concept:

- Projects must work towards a continuum in project ownership from design and construction, to operation and use. This can be achieved by public-private partnership models or other formal means that involve commitment by the clients and/or executing parties to manage the building’s operation and facilities after hand-over. Projects must improve project continuity by obtaining the commitment of key participants involved in design and construction to follow up with evaluations and improvements during the early use phase. Commitment can also be obtained by means commissioning agreements [26] entered at certain stages after the hand-over to ensure that the building functions as intended.
- Projects must regard the process from high-energy efficiency ambitions to good zero emission buildings as a development project in its own right, and base this on close collaboration between the client, executing parties and users. The aim is to achieve willingness among all parties to define, commit to, and pursue ambitious goals, and to achieve a shared understanding of these goals. This can be achieved by focusing on:
    - The availability of adequate time and financial resources, combined with incentives to develop and follow up innovative solutions throughout the entire building process (included hand-over and early use).
    - Collaboration and involvement by means of good leadership and the establishment of effective communication channels and meeting arenas (e.g. workshops).
    - The utilization of available support and expertise (consultants, researchers and enthusiasts) as a means of obtaining sufficient skills and boosting personal involvement among project participants.
- Continuity in staffing is an advantage. Good chemistry between participating individuals and the involvement of dedicated enthusiasts is difficult to plan, but it is clearly a feature of successful processes.
- Projects must involve the end-users at an early stage of planning and design. It promotes the users’ sense of ownership and their understanding of the benefits and challenges linked to the zero-emission concept. This in turn will prepare the project for higher levels of user acceptance

of challenges that arise during the running-in phase following hand-over. It also increases the chance that they use the building in an energy efficient manner in line with the concept.

Zero emission buildings are yet to establish themselves as routine practice in Norway or even internationally. In Norway, public sector clients and the public authorities have assumed a special role in attempting to persuade communities to adopt more energy-efficient ways of living and working. Further research should be carried out into how to advance from this to a situation where executing parties and users perceive ZEB as state-of-the-art, even to the point of demanding energy-efficient solutions. Our research implies that successful pilot projects, involving a satisfied trio of clients, executing parties and users, will be an important driver towards such a development. A modification of the traditional model of the building process is proposed, introducing an additional phase that directs greater focus on continuity during the process, hand-over phase and early use. This model should be tested as part of further pilot buildings and be followed by research. The ZEB concept should preferably also be tested in other countries. There is also an overall need for a broader perspective on buildings` energy performance in the context of the neighbourhoods.

Acknowledgement and funding

This paper has been written at the Research Centre on Zero Emissions Building (ZEB, 2009-2017) and The Research Centre on Zero Emission Neighbourhoods in Smart Cities (ZEN, 2017-2024). The authors gratefully acknowledge funding provided by the Research Council of Norway and the partner companies and organisations of both ZEB and ZEN. We also want to thank all those we interviewed during the pilot projects for their willingness to share their experiences and stories with us.

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