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Article

Let's Get Sociotechnical: A Design Perspective on Zero Energy Renovations

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Abstract
The scaling up of zero energy (ZE) renovations contributes to the energy transition. Yet ZE renovations can be complex and error-prone in both process and outcome. This article draws on theory from sociotechnical design, participatory design, and inclusive design to analyse four recent case studies of ZE renovation/building in the Netherlands. The cases are studied using a mix of retrospective interviews and workshops, as well as ethnographic research. Three of the cases studied are ZE renovations of which two are recently completed and one is in progress, while the fourth case is a recently completed ZE new build. Three of the cases are social housing and one is mixed ownership. The research enquired into the situation of the project managers conducting the processes and also drew on resident experiences. The ZE renovation/builds are analysed as sociotechnical product-service systems (PSSs). The article evaluates how the use values, product values, and result values of these PSSs emerged from the processes. This perspective reveals issues with the usability of the PSSs, as well as with cost structures, technical tweaks, and maintenance agreements. Applying a design perspective provides starting points for co-learning strategies that could improve outcomes. Two example strategies that have potential in this regard are described, using demo dwellings and user manual as PSS prototypes in the early design phase. These and similar strategies could support the professionals in the field in creating successful ZE renovation/building processes.

Keywords
demo dwellings; design thinking; inclusive design; innovation; participatory design; product-service systems; sociotechnical design

Issue
This article is part of the issue "Zero Energy Renovation: How to Get Users Involved?" edited by Tineke van der Schoor (Hanze University of Applied Sciences) and Fred Sanders (CPONH NGO).

1. Introduction

In the Netherlands, zero energy (ZE) renovations of social housing are increasing in number. This is in answer to an ambition to scale up and thus contribute to a transition: the European Union's goals of becoming energy neutral by 2050 (European Commission, 2018).

Yet there are issues slowing down or jeopardizing these processes. Pretlove and Kade (2016) found that with increasing efficiency, energy-saving systems became more complex and failure-prone. Kieft et al. (2017), Lambrechts et al. (2021), and Wilberforce et al. (2021) report mutual blaming: Dutch housing corporations (HCs) see the construction sector as conservative, not developing viable options for affordable energetic renovation, while construction companies (CCs) have to make offers at the lowest price and face technical and financial risks in implementing new technologies. All stakeholders are reluctant to report and investigate any disappointing results, for fear of slowing down the energy transition (Day & O'Brien, 2017).

Some proposals have been made to support the construction field. For example, Janda and Killip (2013, p. 13) argue that there is value in focusing not just on what is being made, but also on *who* does it and *how*: It is "not a matter of reengineering a technical system on paper, it is about reshaping a sociotechnical system by redefining established skills, work practices, and professions on the ground." Lowe and Chiu (2020) and Reindl (2020) showed that the actors in these processes work inventively and creatively. Construction processes have been likened to design processes as more commonly seen in design (Mangnus et al., 2022; Pihl, 2019). Baborska-Narożny and Stevenson (2019) recommended co-learning among all stakeholders (including residents) in ZE construction processes in order to increase the usability of home interfaces. However, Bridi et al. (2022) and Ortiz et al. (2020) report that, in particular, companies are sceptical of user-centred approaches for several reasons. Open innovation may impact intellectual property. Cultural and perspective differences pose communication challenges. In addition, a fragmented supply chain prevents the development of effective feedback mechanisms between the design and use phase of building services. There are strong discipline boundaries within the construction sector (Janda & Parag, 2013; Simpson et al., 2021; Wade & Visscher, 2021). Within and between companies, each "work group is linked (though neither permanently nor absolutely) to a set of socially accepted tasks considered to be its jurisdiction" (Janda & Parag, 2013, p. 42). More insight is needed into the situation of the actors in ZE renovation and building processes and how they could be better supported.

In this article, I adopt a perspective on construction processes as design processes. I focus on the situation of project managers in ZE renovation, both at CCs and HCs. These actors exert "middle-out" influence on other entities, often via innovation (Reindl, 2020). How do they fare in their efforts to create value for the residents? I first present some key notions from the design literature that are applicable to this situation, such as viewing a ZE renovation as a product-service system (PSS; Vezzoli et al., 2021). I apply these notions to a reflection on four case studies of ZE renovation/builds. I then use the perspective to propose strategies that could improve the outcomes for end-users. By grounding these proposals directly in the situations of the project managers, I hope to contribute to co-learning processes that are practicable for the stakeholders of a ZE renovation.

2. Notions From the Design Literature Applied to Zero Energy Renovation/Building Outcomes and Processes

2.1. Zero Energy Renovation/Building Outcomes Viewed as Sociotechnical Product-Service System Designs

The outcome of a sustainable renovation can be termed a PSS in that it fulfils several goals: user-oriented (values: resident satisfaction and comfort), result-oriented (values: energy provision and energy efficiency), and product-oriented (values: viable technology that can be effectively operated; Vezzoli et al., 2021). The goals span social and technical aspects. Thus, ZE renovations are sociotechnical systems. A sociotechnical system includes the effects of consumer behaviour on outcomes (Ceschin & Gaziulusoy, 2019). Design thinking for sociotechnical systems evolved since the 1950s to tackle increasing complexity and fragmentation in industrial contexts such as coalmining, as Klein (2014, p. 138) explains:

> Historically, what seems to have happened is that first engineering, then production engineering, and later systems design have aimed at optimising the technical system as if it was self-contained….One popular reaction…has been to try to optimise the social system as if this, in turn, was self-contained…."Splitting" became institutionalised. Sociotechnical theory makes explicit the fact that the technology and the people in a work system are interdependent….The term "sociotechnical" is inevitably imprecise, almost as imprecise as the term "system"….The important concept to hang on to is that of interdependence.

Given this interdependence of technology use and design, researchers identified early on the role of those "on the shop floor" as key in the success of systems, processes, and change management (Klein, 2014, p. 138). Similarly, Gaziulusoy (2015, p. 369), citing several successful businesses and academic leaders in design research, notes that, in PSS design, "direct or indirect involvement of users has become accepted as one of the key requirements of business success." In drawing a comparison to the construction field at issue here, "those on the shop floor" can be translated to mean both the companies and corporations involved and the end-users of the ZE renovations, i.e., the residents.

2.2. Zero Energy Renovation/Building Processes Viewed as Design Thinking and Participatory Design Processes

The process of a sustainable renovation can be framed in terms of design thinking. Sociotechnical systems thinking became popularised as the concept of "design thinking" in prominent design firms and in business (Bjögvinsson et al., 2012). The same also summarise its tenets (Bjögvinsson et al., 2012, p. 101):

> (1) That designers should be more involved in the big picture of socially innovative design, beyond the economic bottom line; (2) that design is a collaborative effort where the design process is spread among diverse participating stakeholders and competences; and (3) that ideas have to be envisioned, "prototyped," and explored in a hands-on way, tried out early in the design process in ways characterized by human-centeredness, empathy, and optimism.

Design thinking thus emphasizes collaboration and early evaluation. Bjögvinsson et al. (2012) note that these tenets were already commonly accepted in the field of participatory design at that time. The concept of design thinking aligns with important ideas associated with participatory design, for example:

- To regard professionals, including designers, as "reflective practitioners." These are practitioners who are open to the experiences of those they design for, and rather than acting one-sidedly,

embrace having "a reflective conversation with the materials of the situation" (Schön & Bennett, 1996, pp. 7–9) at hand. "Materials" include both users and designers.
- To accept that any design situation and any use situation is more unpredictable and complex than assumed and that one can only come to know about situations by observing them unfold (Suchman, 1987). Suchman (2002, p. 92) argued that the design activity should be studied as an "entry into the networks of working relations—including both contests and alliances—that make technical systems possible."

Viewing ZE construction processes in these terms means observing what happens in them, as well as drawing attention to the explorations of the actors involved and their perceptions and experiences in these explorations.

2.3. Zero Energy Renovation/Building Processes Viewed as Inclusive Design Processes

Many ZE renovation projects concern social housing, large quantities of which have been built industrially since the 1950s. This means that ZE renovation should also be framed in terms of inclusion. Inclusion in democracy and in matters of deliberation has steadily increased in Europe since the 1960s (Christensen et al., 2017), and has also affected design theory. Heylighen and Bianchin (2018) frame inclusive design thinking in terms of "design justice." They offer a practical path in designing for people's diverse needs, with two key principles:

- Address usability in context: Usability is neither a means nor an end in itself but can be measured by "the degree in which agents can convert a resource—in other words, a city, a neighbourhood, a building, a space—into a functioning" (Heylighen & Bianchin, 2018, p. 31). This is a functioning that fulfils these agents' needs. This needs fulfilment "has to do not only with affordance (e.g., walkability, freedom of movement, accessibility), but also with meaning making (e.g., hominess, stigma)" (Heylighen & Bianchin, 2018, p. 31).
- Identify the "worst off": To help determine whether a design is fair, the involvement of the users likely to be worst off due to a design is needed, as others are not necessarily good at determining it for them.

Similarly, Luck (2018) summarizes previous research to state that living with a disability can only be understood from within the experience. Rather than a therapeutic or charitable stance on design, this implies a critical mode of inquiry on design and a new way to understand situations that involves building "relational expertise" (Hendriks et al., 2018). Viewing ZE construction processes in terms of inclusive design means developing the relational expertise to involve the potentially worst off, elicit their experience, and evaluate products as resources for needs fulfilment.

In the following section, I investigate how these design notions shed light on the situation of actors in CCs and HCs in ZE renovation/builds. The research questions are: What are the situations for project managers, viewed from a sociotechnical design perspective? Which possible co-learning strategies could address the issues arising in these situations?

3. Method

3.1. Data Collection and Analysis Approach

In this article, I largely focus on the perspective of the professionals in ZE renovation/building processes, since their actions determine the scope for user involvement and the outcomes for the users, the residents. Some resident perspectives on the actions of the professionals are also elicited. I apply a design perspective, as sketched above, to the descriptions of the processes. Analysing such processes from a design perspective requires broad insight. This is in accordance with Murto et al. (2020) who recommend combining different types of data collection for such broad phenomena as sustainability transitions. Hence, I pragmatically combine both long-term ethnographic research and stakeholder interviews within the same analysis. Murto et al. (2020) recommend conducting retrospective interviews in order to outline processes, find commonalities between processes, tap into the sensemaking of participants, and gather data economically. They state that real-time ethnography additionally captures real-time complexity, the rich ecology of all involved, and the gaps in the process. Day and O'Brien (2017) similarly advocate a broadminded methodological approach of aggregating different case studies and formulating findings into stories that can reveal the "why" of study participants' activities. Therefore, I present the results as reflexive ethnographic narratives from the cases. This is also a preferred approach in participatory design research (Bervall-Kåreborn & Ståhlbrost, 2008; Blomberg & Karasti, 2012), and one that I have applied previously (Boess et al., 2018). As described there, this approach entails leveraging ethnographic documentation and analysis approaches in everyday settings, taking a holistic view of the process, providing descriptive understandings, and showing members' points of view (Blomberg & Karasti, 2012, p. 88). The aim of the analysis is not to present specific cases in their entirety, but rather to extract meaningful stories from them. The idea is to learn equally from all kinds of stories, link the situations found to concepts from design thinking, and interpret them in new ways through thisperspective.

3.2. Study Participants

The cases studied were three ZE renovation processes and one ZE new build process with HCs as clients. One of the ZE renovation processes additionally served owners (mixed ownership). The cases are kept anonymous in order to facilitate an open discussion of the values and issues found. Table 1 shows an overview of the methods and cases studied. The number of housing units involved is given as a range in order to reduce identifiability. Each one of the projects was the first ZE renovation/build for the case study respondents. In that sense, they were all pilots or living lab cases (Keyson et al., 2017). All cases had some degree of extra funding available beyond the direct contract, to cover the gap between affordability and the new type of concept. The processes were not all exactly alike, nor were they studied in the exact same way. They were accessed at different points in time and via different types of respondents (Table 1). The information on them is not complete and depended on the level of access. I was able to interview and observe project managers from CCs and HCs, but not from manufacturers and service companies. I recruited the project managers serendipitously through events and workshops held in connection with the IEBB project (https://www.tudelft.nl/urbanenergy/research/programs/iebb). I asked the professionals whether they would be willing to share their experiences for an academic publication on successes and setbacks in their renovation processes. When they agreed, I held one or more follow-up interviews with them. In addition to the workshops and interviews, I drew on stories from longer-term

Table 1. Overview of the methods and cases studied.

	Building Type	Measures	Respondent	Study Format
Case 1	10–30 units Multi-storey social housing completed three years ago	ZE renovation: Insulation, triple glazing, heat pump, balanced heat recovery ventilation, and solar panels	Client HC building innovation manager (HC project manager)	Structured group session (workshop) with respondents of Cases 1–3; 1.5 hours semi-structured online interview; project meetings
			Various CC members (CC project managers): Communication manager and onsite construction project manager	Long term peripheral participant observation in project meetings and site visits
			Tenants	10 in-home interviews and observations
Case 2	50–100 units Multi-storey social housing apartment; building completed six months ago	ZE renovation: Insulation, triple glazing, heat pump, balanced heat recovery ventilation, battery, and solar panels	Project manager of a research project (RP; RP manager) connected to the construction project	Structured group session (workshop) with respondents of Cases 1–3; 1.5 hours semi-structured online interview
Case 3	10–30 units Social housing; two-storey single-family dwellings; completed six months ago	ZE new build following demolition; same residents. Insulation, triple glazing, heat pump, balanced heat recovery ventilation, and solar panels	HC building innovation manager in charge of the project (HC project manager)	Structured group session (workshop) with respondents of Cases 1–3; 1.5 hours semi-structured online interview
Case 4	250–300 units Mixed ownership, multi-storey social housing apartment complex in the preparation phase; demo unit done	ZE renovation: Insulation, triple glazing, heat pump, direct façade ventilation with central heat recovery extraction, battery, and solar panels	Construction consortium project manager (CC project manager)	Three hours semi-structured interview onsite in demo unit; several demo unit visits

Notes: All cases concerned ZE renovations or builds of social housing (one with mixed ownership). Not interviewed but featured via statements of other stakeholders: Manufacturing company (MC) project managers and service company (SC) project managers.

repeated ethnographic visits to a ZE renovation project in progress. Here, I drew on stories and observations from both professionals and residents.

4. Results

The results are structured into stories of how the project managers envisaged the *product* and the *use-value* of the PSS in the design phase, and stories of how the PSS actually operated in practice after the renovation/build. The *result* values were in all cases envisaged via the current regulations and appropriate calculations.

4.1. How Do the Project Managers Address the Product *of the Product-Service System in the Design Phase?*

The *product* in a ZE renovation PSS is complex. It consists of physical elements and service touchpoints. Physical elements are for example a building's replacement shell, heating and ventilation technology, energy generation and storage technologies, interior ducts, wiring, and information technology. Service touchpoints with the residents' living arrangements are, for example, system interfaces and controls. Around these, there are service arrangements such as rent and energy contracts.

The professionals in the field use various strategies to manage the complexity and design the product part of the PSS. One strategy found is that of collaboratively innovating and standardising elements. In Case 1, the CC, MC, and SC project managers together devised a set of building services compartments (that they call "skids"; Figure 1). They sought to make these as compact as possible and situate them outside of the living space. This served to preserve living space, match balcony dimensions, facilitate efficient maintenance, and work towards upscaling. In Case 4, too, the CC and MC project managers collaboratively developed new ventilation elements for the project at hand. They additionally developed a novel service touchpoint: an app-based system to control temperature, ventilation, and lighting in the home. In Case 3, the HC project manager collaborated with the SC project managers to develop a novel in-house display. The display enables residents to control environmental parameters and alerts them to energy consumption.

Another strategy to manage the complexity in the design is to involve residents early on, which was done in Cases 2 and 3. In both, the communication between professionals and residents started several years ahead of the renovation. This made it possible to align the communication with the design decisions. In Case 2, the RP manager recounted how the CC project managers drew on expertise from communication specialists early on to get the residents on board with the communication flow via a diversity of channels, including digitally. There was a period of prototyping ahead of the actual renovation, with residents involved. This created learnings, not just on the building technology, but also on the mutual expectations.

In Cases 1, 2, and 4, the partners realized a full scale, largely functional demo dwelling. A demo dwelling reveals how the components come together and potentially serves to learn and adapt the solution. An added benefit for the construction partners is that it persuasively demonstrates their competence to build, thus creating trust with the residents. Yet the project managers in all three cases experienced that these very qualities also carry a risk: Construction professionals and residents alike can take them to present the specific solution and not see that they could still be changed. It is challenging for all involved to visualize alternatives for the concrete things they see.

4.2. How Do the Project Managers Address the Use *of the Product-Service System in the Design Phase?*

The *use* in a ZE renovation PSS refers to the expected values that are obtained in its operation, for example, comfort and satisfaction. How did the stakeholders in the cases look ahead to use?

While the CCs in Cases 1 and 4 created fully operational demo dwellings as mentioned, they were not able to fully profit from them. From a design perspective, a way to profit from them would be to use them to anticipate the future interactions the residents would have with their dwellings. However, in both cases, the entire process had a relatively short time frame. This limited the usefulness of the demo dwellings in this regard.

In Case 1, the demo apartment was created just after the consent of the residents for the project had been obtained. The construction started shortly after. The CC project managers mainly used the demo dwelling as an office for close contact with the residents, for marketing purposes, and to explain the products, but not to evaluate or iterate on anticipated use. The renovation of the rest of the units was later realized in the exact same way in spite of the fact that problems could already have been anticipated with the demo apartment, as will be shown below.

In all cases 1, 2, and 4, in which a demo apartment was built, some aspects shown in the demo apartment were only preliminary instantiations of the concept, while appearing finished. The CC project managers in Case 4 actively sought the residents' feedback and also displayed the feedback they collected in the demo house itself, thus making the early evaluation cycle tangible and accessible. However, some elements of the prototypes differed from the way the technology would function in the house, while this was not communicated to the residents. The residents invested a lot of energy into the evaluation of those elements. The confusion about what is or is not the intended design eventually affected the residents' trust in the proposals negatively.

Cases 1 and 4 reveal a pitfall: While the partners had a great commitment to realizing innovative designs and prototypes, they could not reap the full benefits from them. The reasons were overwhelming complexity, time shortage, and insufficient capability to utilize observed functioning for design iterations.

In Case 1, the CC and MC project managers were very aware of the importance of a particular aspect of future functioning: The residents' future interaction with the ventilation filters. Ventilation units have filters that have to be serviced by cleaning them every six to 12 weeks, depending on the level of use. The SC project manager was pessimistic about this in the planning phase, stating that "the residents will not do it anyway…residents will do the strangest things and damage the system." The project team made efforts to address this use issue but did not come to a clear decision on it. The final building services compartment design was more suited for professional servicing but was not accessible without making a service appointment with a resident. As a consequence, the filter servicing became a task for the residents after all, in spite of the pessimism. When all product decisions had been made, as the last step, the CC communication manager created a manual for the residents by combining the existing manuals of the separate technologies.

In Case 2, conversely, the RP manager described that CC project managers managed the technical design and the communication with the residents in tandem. The CC project managers had knowledge of design thinking processes and brought this thinking into the process. In their design, they located the heating and ventilation technology close to the residents' living space and within reach, which made it well-aligned with the residents' living practices. The CC project managers engaged with expected use by producing a custom-made manual for the specific configuration of the renovation, in close collaboration with the manufacturers of the technologies and the residents themselves.

In Case 3, the HC project manager actively anticipated the future functioning of the systems in the home. In his view, the communication process with the residents serves to create understanding and manageability of the technical implementations for future managers and residents alike. The HC project manager commissioned a sophisticated digital system from an external IT company that did three things: (a) give residents control over their house via a control panel by the living room door to keep track of system functioning and energy use; (b) enable the HC to monitor the performance of the building services; and (c) streamline maintenance calls. After the residents moved in, the HC project manager explained the operation of the systems to them verbally. They received no manual since the system itself was expected to provide guidance.

4.2.1. Synthesis From a Design Perspective

The examples on the design of the *products* and the *use* of the PSS have shown that some of the professionals' considerations were one-sided, and that demo houses were only partially used as prototypes for future interactions. In Cases 1 and 2, the professionals used the creation of the manual to reflect on the expected use of the technologies. While no manual can compensate for an unusable design, the creation of a manual or a similar representation of use could conceivably be part of an anticipatory evaluation framework of how a house will function to create use-value. In addition, it would be valuable to designate clearly in prototypes what is still open to iteration and how certain elements of the prototype are intended. Then the design rather than the prototype can be evaluated. If enough time is taken for this, the design can still be adapted. From a design perspective, earlier prototyping, anticipation of future use, and iteration could help facilitate resident satisfaction and comfort and an effective technology operation later. A greater diversity of purpose-specific prototypes might be more cost- and time-efficient early on and facilitate iteration. In the design field, it is often assumed that prototypes should seem unfinished in order not to generate inaccurate expectations. Prototypes should be created with a specific evaluation goal in mind. A conceivable approach is to create demo houses or demo situations where technology can be tested ongoingly, and user manuals in order to evaluate the expected use.

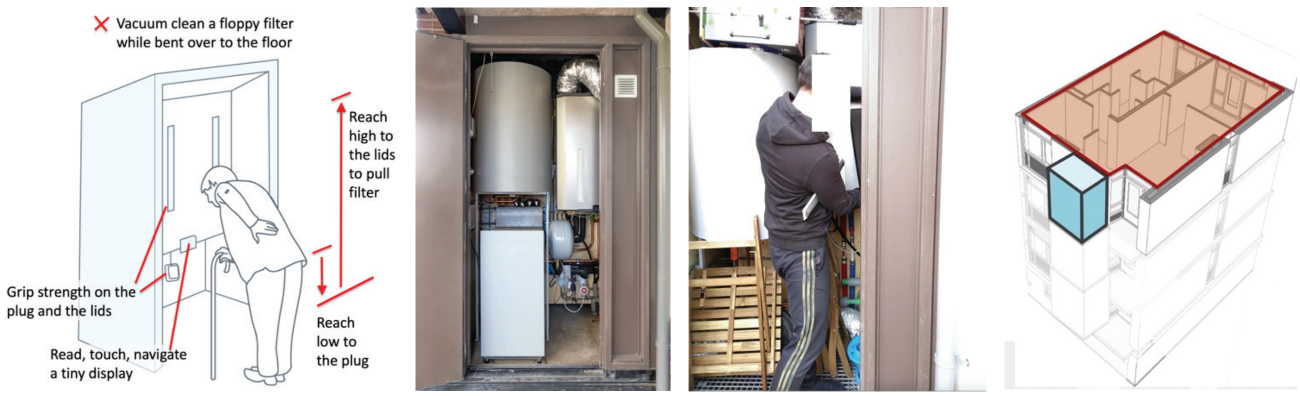
4.3. How Does the Product-Service System Operate After Renovation/Building Completion in Terms of the Product*,* Use*, and* Result *Values?*

In the executed projects, new insights emerged for the stakeholders when they entered the phase of use. Overall, the residents in Cases 1–3 were very satisfied with the renovation/build. There was a significant increase in comfort and quality of the dwelling for them. However, the project managers in the case studies made many discoveries about their PSS in this phase.

In Case 1, the CC project managers commissioned a marketing agency to assess resident satisfaction some months after completion. The residents were generally very happy with the increased comfort and the greatly improved exterior aesthetics of their apartment block. However, the residents also placed many service calls related to broken down or underperforming heating and ventilation systems. For these issues, the CC project manager eventually planned a "service day." They rallied all of the installation partners and planned visits with all residents on the same day. The researcher was also present on that day. The CC project manager's plan was to tweak the systems and provide the residents with extensive instructions and opportunities to ask questions. Instead, due to the pressure of resolving all issues at once, the interaction with the residents boiled down to asking them whether they had read the manual and whether they had any questions. The residents did not have any questions. Over the months that followed, their difficulties with the systems persisted or new ones emerged. The CC project managers still came back to resolve final issues more than two years after the renovation, though formally their responsibility had ended, because they felt the commitment to make the building work. An issue could not be resolved: the residents' access to the building services compartment (Figure 1). It proved to be physically impossible for some of the residents to clean the filters, and it was a difficult task for all of them (Figure 1a). This is worth noting since in the preparation phase one of the key worries of the professional stakeholders had been that residents would be unwilling to clean the filters. Besides the ergonomic difficulties or even impossibilities, the residents experienced the compartment as a confusing and unpleasant space that does not belong to their home space (Figure 1d). When opening the door to the compartment, residents were presented with a bewildering array of technology (Figure 1b). Several of the residents interpreted the compartment as a shed, because it was located outside of their apartment. There were some small spaces left over in the compartment, which some residents proceeded to fill with personal effects (Figure 1c). In one case, this resulted in severing a ventilation duct.

In Case 2, the heating and ventilation configuration proved to be a better fit with the residents' lives than in Case 1. Upon completion, communication technology was again employed as an extension of the earlier resident communication process. The RP project manager describes that the CC project managers placed displays in the stairwells informing about overall energy production and use. In addition, all residents received a tablet computer for information related to their own apartment and had access to an app with the same information. Not all residents liked to use the tablet computers, but they also had access to personal contacts for any questions. After the renovation, the CC project manager personally stayed engaged in any needed troubleshooting. The CC project managers also made arrangements with two residents who showed an affinity with the renovation and trained them to become a contact point for the other residents. When these two residents get questions they cannot answer, they can call the CC project managers. The benefit beyond the resolution of technical issues is that all residents greatly appreciate that two residents have this social role. The project managers' approach was to welcome any comfort complaints from the residents in the period after the renovation and work to address them right away. These examples from Case 2 show how a social approach has benefits in addressing technology issues. It can do so in a way that does not overwhelm the professional stakeholders' resources by supplementing personal contact with digital communication. The professionals were able to take away learnings for the next iterations of the product.

In Case 3 (new build single-family dwellings), the HC project manager reported that the control panel in the home functioned as a link between the residents' lives and the functional make-up of the home. He said that the residents were now able to take charge of their home and its energy use and had autonomy in responding to it. He received fewer complaints about energy bills. However, only a third of the residents used the control panel actively. The monitoring system had additional benefits: In some cases, it was possible to respond to maintenance issues remotely before residents even noticed them, via resets. When a resident calls to report a problem, the relevant data is immediately available to the service partner. The service partner can do remote troubleshooting and, in some cases, guide a resident in doing a minor repair or reset. However, there were resident complaints about too much automation. This continues to be tweaked, particularly since it also extends to hallway lights. In addition, when the HC project manager visited the residents in an extensive evaluation round of 1.5-hour visits per home, he found that two households had used the ventilation unit filter to replace the filter of the cooker extraction hood. The filters were too similar for the resident to be able to distinguish. The ventilation units were



(a) (b) (c) (d)

Figure 1. The building services compartment in Case 1. **(a)** Unrealistic expectations are put on a resident to service a filter unit; **(b)** the building services compartment on the balcony, all services combined in one space; **(c)** the building services compartment being interpreted as a shed and a person contorting their body in order to reach the filters for cleaning and not knowing where to leave the lid; **(d)** the building services compartment being interpreted as a space that does not belong to the home.

in the attic space (accessible via a permanent staircase), which raises questions about whether the residents will keep servicing filters regularly. Lastly, some residents had concerns about data privacy with the new system.

Case 4 was still in the concept stage and not yet executed as a renovation. However, the demo apartment that was realised already brought some findings. Regular guided tours enabled the residents to provide comments that could be addressed before scaling up. For example, the façade should provide space for window coverings, which the prototype façade did not provide. However, the residents found it more difficult to comment on the heating and ventilation technology and its interfaces. Providing novel proposals in this regard may look advanced and more difficult to critique for residents. Even the project managers did not completely oversee whether the new interfaces would align well with residents' living practices, or how to adjust if they did not. As a project manager remarked: "We thought of what we are developing primarily in terms of things we provide, and not so much in terms of how people would interact with them in the course of their lives." The CC project manager expressed the desire to put into practice the learnings gleaned through their demo house set-up.

Another set of issues arose after the completion of the renovation/build in Cases 1–3. These pertained to the management of the buildings. There were issues with an unclear costing structure which took the HC project managers a lot of time to investigate. The performance and costs were not fully as expected. In Cases 1 and 3, a resident had inadvertently deactivated a fuse, thus blocking the gains from their allocated solar panels. In Case 1, higher heating costs arose because some residents left the heating on a maximum setting for extended periods of time. In both Cases 1 and 2, the heating performance was lower than expected, requiring some error searching to fix it. In Case 3, there was an issue with apparent excessive hot water use that turned out to be a reading error within the system. During the time-intensive error searching activities, the HC project managers experienced a decline in engagement from the manufacturers and service partners after an initial period of close collaboration. The HC project manager of Case 1 grew exasperated with his inability to manage the costs of the apartment block due to a lack of information. The HC project manager of Case 3 concluded that the business model of the performance guarantee does not work, because there is no real incentive for the service partner to stay engaged. Both HC project managers eventually took the step of cancelling the performance contract with the service partners. The reasons they gave were that these parties were unwilling or unable to investigate malfunctioning effectively or give sufficient insight into the performance and costs of the systems. In Case 1, the cancellation happened three years after the renovation, after a long period of attempting to optimize the system. In Case 3, the manager already decided to do this a few months after the renovation. Both HC project managers then teamed up with specialized maintenance partners and successfully optimized the systems. The HC project manager of Case 3 set up their own maintenance business model. Through a greater percentage of remote diagnosis and repair, they were able to offset the information technology investments against the saving in onsite service calls.

4.3.1. Synthesis From a Design Perspective

The post-completion findings reveal a significant investment of energy in the three completed cases. The phase provided many opportunities for reflective learning on the implemented PSS. All managers of the cases had underestimated the complexity of the post-completion phase. Time not spent in the design phase became time spent later. In-depth, contextual design and evaluation strategies focusing on use in the design phase could conceivably have helped. The value of such strategies lies in a more reliable prediction of resident satisfaction and energy efficiency since residents would be better able to engage with the heating and ventilation technology. The project managers of all partners met the unexpected setbacks with resilience and resourcefulness. Possibly, they operate partly out of idealism to see ZE renovations/builds succeed. Yet, it seems like manufacturers, service partners, and CCs currently do not have sufficient business models to manage the phase after completion. One HC project manager created their own business model for this phase. There is space for new business models to manage the post-completion phase and capture the learnings. Another possibility would be to generalize the findings from each project beyond the specific, concrete product that has been implemented. The more generalized findings can provide input for new processes starting up. Such input could for example be standardized in new regulations.

5. Discussion

With regard to the research questions on the situations for project managers, viewed from a sociotechnical design perspective, and which possible co-learning strategies could address the issues arising in these situations, the results have shown that the post-completion phase provides many insights that could potentially have been gained earlier.

5.1. The Cost of Gaining Design Insights Only Post-Renovation/Build

In the cases studied, the post-completion phase was a phase of design that extended significantly beyond the completion of the project. Technology is tweaked, the residents go through a process of integrating the new technology into their life practices—more or less successfully—and the real performance of the building emerges. In two cases, new business models for building management even emerged during this phase.

The renovations in Cases 1–3 were successful overall and the residents were satisfied with the results. Yet the setbacks, if scaled up without learning from them, would have the potential to inhibit rather than accelerate uptake. If other residents hear about them, it might make it more difficult to gain consent in the future. In addition, the amount of effort that the professionals now put into post-renovation tweaks does not seem scalable.

5.2. The Potential of Gaining Design Insights Pre-Renovation/Build

Many of the observed situations and insights could conceivably have been addressed earlier in the process. Applying a design thinking perspective would mean framing new proposals and new products in terms of the users' future interactions with them. For example, the interaction with filter systems can be tested using prototypes according to ergonomic criteria. That way, efficiency can be gained, new directions can be discovered, and transferable learnings generated. Hyysalo et al. (2007) already discussed how users often shape technologies through use and appropriation, regardless of their technical understanding. This shaping could be a resource for innovation. Early user involvement in technology use and design—in other words, a sociotechnical approach—elicits knowledge on whether residents will be able to convert the resource ZE housing into a functioning that fulfils their needs (Heylighen & Bianchin, 2018). More certainty can be gained on who is included in and excluded from using the design. From a design perspective, is it possible to prototype and evaluate the technical measures in advance, create more innovation and certainty, and, with enough time available, iterate on them to better fulfil needs and save time later.

5.3. Co-Learning Opportunities

By taking the situations in the field as the point of departure and applying a design perspective, the research has identified new co-learning opportunities. The opportunities include using demo dwellings more for design and iteration and designing these demos themselves more iteratively so that well-defined use issues can be addressed. Demo apartments could potentially acquire the role of a participatory design studio. Currently, intermediaries tend to view them as one-way communication tools for showcasing intended technology, rather than for mutual sociotechnical learning engagements. In addition, the user manual is an interesting artefact in that it could help consortia study and evaluate earlier whether the combination of technologies will work in the use context. Lastly, in one of the cases, communication technology was shown to be a valuable tool in scaling up the residents' involvement early on in a project. The opportunities identified here are close to the practices in the field and could answer the calls of Baborska-Narożny and Stevenson (2019) and Bridi et al. (2022) for co-learning strategies. If manufacturers were also involved in such places of encounter, then these places could function as living labs (Keyson et al., 2017), while maintaining confidentiality as needed. I have also found that the "middle actors" (Reindl, 2020) face significant challenges in aligning their consortia toward a successful post-construction phase. They could benefit from more experience sharing to learn about potential setbacks and opportunities earlier. This could take the form of fora and workshops to exchange experiences. In addition, new technologies, like digital twins and building information modelling, could become carriers of these insights in order to help better predict the performance of renovations.

5.4. User-Product Interaction in a Sociotechnical View

The interactions of residents with their homes take place on the level of user-product interaction yet cannot be framed as a technic-centric problem only, as Ceschin and Gaziulusoy (2019) see it. One might question whether, in the interest of energy efficiency and upscaling, professionals are too quick to accept a reduced view of what it means to interact as a human with technology in a space or environment. Rather, it is also at the micro-level of interactions that societal issues, such as inclusion or exclusion, manifest.

5.5. Limitations

The cases I have studied may or may not have been typical of the process of ZE renovation/building. Further research should verify the findings in a more structured manner and assess whether the findings and design perspective contributions are transferable. To ensure this, the case studies have been described in such a way as to allow for comparison (Graneheim & Lundman, 2004).

This research has highlighted the relevance of early user involvement in design to address use issues. A limitation of the proposed co-learning opportunities may be that they require the skills of the professionals in engaging with non-professional voices. Such skills are likely to be less developed and present in the construction field since the bulk of the stakeholders' activities lies in the design and planning phase (Konstantinou & Heesbeen, 2022). These skills may be difficult to integrate into the disciplines that pervade the field (Janda & Parag, 2013). Dialogues are a topic of design in themselves (Roosen et al., 2020) and require "relational expertise" (Hendriks et al., 2018). A direction for future research in this regard would be to integrate the skills sets and knowledge from the field of post-occupancy evaluation in the design phases (Guerra-Santin & Tweed, 2015).

6. Conclusions

This article has employed case studies to study the reality of three ZE renovation processes and one ZE building process. While many things go smoothly and turn out satisfactory for residents and HC managers, some do less so. Issues with usability, costing models, and energy efficiency were found. It would be desirable to make it easier for the professional stakeholders in the field to manage sustainable renovations/builds, because of the widely perceived urgency of the energy transition. By drawing on design perspectives, this article has identified new co-learning opportunities that could potentially address the issues found. These opportunities promote both collaboration of the stakeholders in the field and resident involvement, which include creating spaces for learning and iteration through demo dwellings. They also include creating concepts of future interaction and use of the PSS of ZE renovation/build during the design phase. Creating more iterative and evaluative strategies for the field has the potential of helping the energy transition speed up.

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Conflict of Interests

The author declares no conflict of interests.

References

Baborska-Narożny, M., & Stevenson, F. (2019). Service controls interfaces in housing: Usability and engagement tool development. *Building Research & Information*, *47*(3), 290–304. https://doi.org/10.1080/09613218.2018.1501535

Bervall-Kåreborn, B., & Ståhlbrost, A. (2008). Participatory design: One step back or two steps forward? In D. Hakken, J. Simonsen, & T. Robertson (Eds.), *PDC '08: Proceedings of the Tenth Anniversary Conference on Participatory Design 2008* (pp. 102–111). Association for Computing Machinery.

Bjögvinsson, E., Ehn, P., & Hillgren, P. A. (2012). Design things and design thinking: Contemporary participatory design challenges. *Design Issues*, *28*(3), 101–116.

Blomberg, D. J., & Karasti, H. (2012). Ethnography: Positioning ethnography within participatory design. In J. Simonsen & T. Robertson (Eds.), *Routledge international handbook of participatory design* (pp. 106–136). Routledge.

Boess, S., Silvester, S., de Wal, E., & de Wal, O. (2018). Acting from a participatory attitude in a networked collaboration. In L. Huybrechts, M. Teli, A. Light, Y. Lee, C. Di Salvo, E. Grönvall, A. M. Kanstrup, & K. Bødker (Eds.), *Proceedings of the 15th Participatory Design Conference: Short papers, situated actions, workshops and tutorial* (Vol. 2, pp. 1–6). Association for Computing Machinery.

Bridi, M. E., Soliman-Junior, J., Granja, A. D., Tzortzopoulos, P., Gomes, V., & Kowaltowski, D. C. C. K. (2022). Living labs in social housing upgrades: Process, challenges and recommendations. *Sustainability*, *14*(5), Article 2595.

Ceschin, F., & Gaziulusoy, İ. (2019). *Design for sustainability: A multi-level framework from products to socio-technical systems*. Routledge.

Christensen, H. S., Jäske, M., Setälä, M., & Laitinen, E. (2017). The Finnish citizens' initiative: Towards inclusive agenda-setting? *Scandinavian Political Studies*, *40*(4), 411–433.

Day, J. K., & O'Brien, W. (2017). Oh behave! Survey stories and lessons learned from building occupants in high-performance buildings. *Energy Research & Social Science*, *31*, 11–20.

European Commission. (2018). *2050 long-term strategy.* https://ec.europa.eu/clima/eu-action/climate-strategies-targets/2050-long-term-strategy_en

Gaziulusoy, A. İ. (2015). A critical review of approaches available for design and innovation teams through the perspective of sustainability science and system innovation theories. *Journal of Cleaner Production*, *107*, 366–377.

Graneheim, U. H., & Lundman, B. (2004). Qualitative content analysis in nursing research: Concepts, procedures and measures to achieve trustworthiness. *Nurse Education Today*, *24*(2), 105–112.

Guerra-Santin, O., & Tweed, C. A. (2015). In-use monitoring of buildings: An overview of data collection methods. *Energy and Buildings*, *93*, 189–207. https://doi.org/10.1016/j.enbuild.2015.02.042

Hendriks, N., Huybrechts, L., Slegers, K., & Wilkinson, A. (2018). Valuing implicit decision-making in participatory design: A relational approach in design with people with dementia. *Design Studies*, *59*, 58–76.

Heylighen, A., & Bianchin, M. (2018). Building justice: How to overcome the inclusive design paradox? *Built Environment*, *44*(1), 23–35.

Hyysalo, S., Johnson, M., & Heiskanen, E. (2007). Design-use relationships in sociotechnical change. *Human Technology*, *3*(2), 120–126.

Janda, K. B., & Killip, G. (2013). Building expertise: Renovation as professional innovation. In R. L. Henn & A. J. Hoffman (Eds.), *Constructing green: The social* *structures of sustainability* (pp. 35–55). MIT Press. https://doi.org/10.7551/mitpress/9780262019415.003.0002

Janda, K. B., & Parag, Y. (2013). A middle-out approach for improving energy performance in buildings. *Building Research & Information*, *41*(1), 39–50. https://doi.org/10.1080/09613218.2013.743396

Keyson, D. V., Guerra-Santin, O., & Lockton, D. (Eds.). (2017). *Living labs*: *Design and assessment of sustainable living*. Springer.

Kieft, A., Harmsen, R., & Hekkert, M. P. (2017). Interactions between systemic problems in innovation systems: The case of energy-efficient houses in the Netherlands. *Environmental Innovation and Societal Transitions*, *24*, 32–44.

Klein, L. (2014). What do we actually mean by "sociotechnical"? On values, boundaries and the problems of language. *Applied Ergonomics*, *45*(2), 137–142.

Konstantinou, T., & Heesbeen, C. (2022). Industrialized renovation of the building envelope: Realizing the potential to decarbonize the European building stock. In E. Gasparri, A. Brambilla, G. Lobaccaro, F. Goia, A. Andaloro, & A. Sangiorgio (Eds.), *Rethinking building skins: Transformative technologies and research trajectories* (pp. 257–283). Woodhead Publishing.

Lambrechts, W., Mitchell, A., Lemon, M., Mazhar, M. U., Ooms, W., & van Heerde, R. (2021). The transition of Dutch social housing corporations to sustainable business models for new buildings and retrofits. *Energies*, *14*(3), Article 631.

Lowe, R., & Chiu, L. F. (2020). Innovation in deep housing retrofit in the United Kingdom: The role of situated creativity in transforming practice. *Energy Research & Social Science*, *63*, Article 101391. https://doi.org/10.1016/j.erss.2019.101391

Luck, R. (2018). What is it that makes participation in design participatory design? *Design Studies*, *59*, 1–8.

Mangnus, A. C., Vervoort, J. M., Renger, W. J., Nakic, V., Rebel, K. T., Driessen, P. P., & Hajer, M. (2022). Envisioning alternatives in pre-structured urban sustainability transformations: Too late to change the future? *Cities*, *120*, Article 103466.

Murto, P., Hyysalo, S., Juntunen, J. K., & Jalas, M. (2020). Capturing the micro-level of intermediation in transitions: Comparing ethnographic and interview methods. *Environmental Innovation and Societal Transitions*, *36*, 406–417.

Ortiz, M., Itard, L., & Bluyssen, P. M. (2020). Indoor environmental quality related risk factors with energy-efficient retrofitting of housing: A literature review. *Energy and Buildings*, *221*, Article 110102.

Pihl, D. (2019). *The making of an energy renovation: Knowing & acting on energy-saving features through design processes* [Doctoral dissertation, Aalborg University]. Aalborg University's Research Portal. https://vbn.aau.dk/en/publications/produktionen-af-en-energirenovering-erkendelse-amp-handling-af-en

Pretlove, S., & Kade, S. (2016). Post occupancy evaluation of social housing designed and built to Code for Sustainable Homes levels 3, 4 and 5. *Energy and Buildings*, *110*, 120–134. https://doi.org/10.1016/j.enbuild.2015.10.014

Reindl, K. (2020). Agency and capacity in the planning and design phase of building renovations. *Energy Efficiency*, *13*(7), 1409–1425.

Roosen, B., Huybrechts, L., Devisch, O., & Van den Broeck, P. (2020). Dialectical design dialogues: Negotiating ethics in participatory planning by building a critical design atlas. *Urban Planning*, *5*(4), 238–251. https://doi.org/10.17645/up.v5i4.3294

Schön, D., & Bennett, J. (1996). Reflective conversation with materials. In T. Winograd (Ed.), *Bringing design to software* (pp. 171-189). Addison-Wesley.

Simpson, K., Murtagh, N., & Owen, A. (2021). Domestic retrofit: Understanding capabilities of micro-enterprise building practitioners. *Buildings and Cities*, *2*(1), 449–466. https://doi.org/10.5334/bc.106

Suchman, L. (1987). *Plans and situated actions: The problem of human-machine communication*. Cambridge University Press.

Suchman, L. (2002). Located accountabilities in technology production. *Scandinavian Journal of Information Systems*, *14*(2), 91–106.

Vezzoli, C., Ceschin, F., & Diehl, J. C. (2021). Product-service systems development for sustainability: A new understanding. In C. Vezzoli, B. Garcia Parra, & C. Kohtala (Eds.), *Designing sustainability for all: The design of sustainable product-service systems applied to distributed economies* (pp. 1–21). Springer.

Wade, F., & Visscher, H. (2021). Retrofit at scale: Accelerating capabilities for domestic building stocks. *Buildings and Cities*, *2*(1), 800–811. https://doi.org/10.5334/bc.158

Wilberforce, T., Olabi, A. G., Sayed, E. T., Elsaid, K., Maghrabie, H. M., & Abdelkareem, M. A. (2021). A review on zero energy buildings: Pros and cons. *Energy and Built Environment*. Advance online publication. https://doi.org/10.1016/j.enbenv.2021.06.002

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