Urban Planning (ISSN: 2183-7635)
Year, Volume, Issue, Pages X–X
https://doi.org/10.17645/up.vXiX.XXX

Article

Let's get sociotechnical: a focus on use during the design of zero energy renovations

Stella Boess [1]*

[1] Faculty of Industrial Design Engineering, Delft University of Technology, Delft, the Netherlands, s.u.boess@tudelft.nl

* Corresponding author

Abstract

This paper reports on ethnographic and interview studies on Zero Energy refurbishments and builds of social housing in the Netherlands. It draws on theory from sociotechnical design and participatory design to analyse three case studies of completed sustainable renovation processes of social housing and one case study that is still in progress. The research consisted of retrospective interviews, combined with long-term ethnographic participant observation. The research enquired into the situations for middle actors in conducting ZE refurbishment / build processes, and does a design perspective reveal paths towards co-learning that includes tenants' experiences? ZE refurbishment / build processes are framed in terms of Product Service Systems that address results, products and use. The research showed that while the projects generally went well and tenants were satisfied, some issues arose in usability of the results, as well as cost structures, technical tweaks and maintenance agreements. The research also traced the tools and techniques the professionals used to develop and evaluate the PSS before and after the project. Applying a design perspective showed that two techniques, building a demo dwelling and creating a user manual, could be used more to develop and evaluate the use of the PSS. This could potentially improve usability and inclusion and also create efficiency in the processes. With that, the techniques could support the professionals in the field in creating and using learnings from ZE refurbishment / build processes.

Keywords

case studies; demo dwellings; design thinking; participatory design; inclusive design; sociotechnical design; Product Service Systems; evaluation; innovation

Issue

1. Introduction

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

Yet there are issues slowing down or jeopardizing these processes. Lambrechts et al (2021), Wilberforce et al (2021) and Kieft et al (2017) report mutual blaming: Dutch housing corporations see the construction sector as conservative and not developing viable options for affordable energetic refurbishment, while construction companies have to make offers at the lowest price and face technical and financial risks in implementing new technologies. Pretlov and Kade (2016) found that with increasing efficiency came complexity, and energy saving systems are prone to systems failure.

Baborska-Narożny & Stevenson (2019) charted the issues with usability of interfaces in realised housing and recommended co-learning processes for all stakeholders of a ZE refurbishment or build process. However, Bridi et al (2022) and Ortiz, Itard & Bluyssen (2020) report sector companies' scepticism of user-centred approaches and of open innovation which may impact intellectual property, cultural and perspective differences, and a lack of feedback mechanisms between the design and the actual performance and user experience of building services due to a fragmented supply chain. It is challenging for stakeholders to investigate and report any disappointing results (Day & O'Brien, 2017) for fear of slowing down or damaging the energy transition. More insight is needed into the situation of the project managers active in the construction sector, as well as their counterparts in housing corporations, in order to understand how they could be supported better. These actors exert "middle-out" influence to other entities, often via innovation (Reindl, 2020). Their processes have been likened to design processes as more commonly seen in design (Pihl, 2019). Reindl (2020) and Lowe & Chiu (2020) showed that they work inventively and creatively. Yet there are also strong discipline boundaries in the construction sector (Wade and Visscher, 2021); Simpson et al., 2021; Janda and Parag, 2013). 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 and Parag, 2013, p. 42). Janda and Killip (2013) argue that there is value in focusing not just on what is being made, but also *who* does it and *how*: that it is "not a matter of reengineering a technical system on paper, it is about reshaping a socio-technical system by redefining established skills, work practices, and professions on the ground."

In this paper, we apply a design perspective to the situation of project managers in ZE renovation, focusing on project managers both at construction companies and housing corporations. How do they fare in their efforts to create value for clients and tenants? Could and do they facilitate co-learning, do they involve the tenants? We first present some key notions from the design literature that are applicable to this situation, such as viewing a ZE refurbishment as a Product Service System (Vezzoli et al., 2021). We then apply these notions to a reflection on four case studies of ZE renovations and develop proposals to address the outcome for end users. By grounding these proposals directly in the situations of the project managers, we hope to contribute to facilitating co-learning processes for all stakeholders of a ZE refurbishment.

1. ZE refurbishment/build as the design of a sociotechnical Product-Service-System

1.1 ZE refurbishment / build as the design of a sociotechnical Product-Service-System

The outcome of a sustainable renovation can be termed a Product-Service-System (PSS) in that it fulfils several goals: use-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). In this view, ZE refurbishments are complex systems that span social and technical aspects. How can sociotechnical design be understood? Ceschin & Gaziulusoy (2019) trace how ecodesign evolved since the 1960s from a focus on specific products (for example, their lifecycle) to a more encompassing sociotechnical systems view that also includes the effects of consumer behaviour on outcomes. In design for industrial contexts and workplaces, sociotechnical design thinking evolved since the 1950s to tackle increasing system complexity. Klein (2014) 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."

This interdependence of both technology use and technology design was identified in industrial processes such as coal mining. From the start, researchers saw the role of those 'on the shop floor' as key in managing the success of systems, processes and change management (Klein, 2014). Similarly, Gaziulusoy (2015, p. 369), citing several successful business 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.

1.2 Design thinking and participatory design

Sociotechnical systems thinking became popularised as the concept of *design thinking* in prominent design firms and in business (Bjögvinsson et al, 2012). They summarise its tenets:

"(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".

Bjögvinsson et al (2012) note that these tenets were already commonly accepted in the field of Participatory Design, a similar and parallel development to sociotechnical design thinking. The concept of design thinking aligns with important theoretical ideas in design theory, for example

- To regard professionals, including designers, as "reflective practitioners": professionals who are open to experiences of those they design for, and who embrace having "a reflective conversation with the materials of the situation" at hand (Schön, 1983) – in which 'materials' includes users and designers - rather than that professionals one-sidedly determining courses of action, and
- To accept that any design situation and any use situation is more unpredictable and complex than we assume, and that we can only come to know about situations through what happens in them, through observation (Suchman, 1987). Suchman (2002) argued that we should study design activity as an "entry into the networks of working relations – including both contests and alliances - that make technical systems possible".

1.3 User involvement as a societal issue: inclusive design

Many ZE renovation projects concern social housing, large quantities of which has been built industrially since the 1950s. This means that ZE renovation should also be framed in terms of inclusive design, besides industrial design and systems ecodesign. Next to the developments in industrial design and consumer products design, inclusion in democracy and in matters of deliberation has also steadily increased in Europe since the 1960s (Christensen et al, 2017). Heylighen & Bianchin (2018) frame inclusive design thinking in terms of "design justice" and offer a practical path through the problem of 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" that fulfils their needs. This "has to do not only with affordance (e.g. walkability, freedom of movement, accessibility), but also with meaning making (e.g. hominess, stigma)"
- 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 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).

In the following, we will investigate whether these notions can shed light on the situation of actors in construction companies and housing corporations in ZE refurbishment / build. The research questions we address are, what are the situations for middle actors in trying to make ZE housing work, and how do design notions provide possible paths to co-learning processes that also include tenants' experiences?

2. Method

We focus on the professional stakeholders and how they define and thus shape and constrain the processes. As we have done in previous, similar analyses (Boess et al, 2018), in this paper we present reflexive ethnographic narratives from observed processes as well as from interviews with stakeholders (Blomberg and Karasti 2012, Bervall-Kåreborn and Ståhlbrost 2008). As described earlier, this approach entails leveraging ethnographic documentation and analysis approaches in everyday settings, taking a holistic view on the process, providing descriptive understandings and showing members' point of view (Blomberg and Karasti 2012, p. 88). This paper pragmatically combines long-term ethnographic involvement with stakeholder interviews. Murto et al (2020) promote a broad methodological basis for such broad phenomena as sustainability transitions. Such methods need to be able to span the levels from macro-level conditions for transitions, to the micro-level of communities' and individuals' daily life and practices where changes in consumption occur. Particularly, they point to the role of intermediaries in shaping transition processes: people who in some capacity, formal or informal, aim to facilitate a result. Murto et al (2020) compare retrospective interviews and real-time ethnography in this context and conclude that the former is suitable for outlining processes, finding commonalities between processes, tapping into the sensemaking of participants and gather data economically, while the latter captures real-time complexity, the rich ecology of all involved, and the gaps in the process. We thus use both techniques. 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 occupant behaviour.

We employed a mixed approach here: a retrospective interview approach, complemented by real-time ethnographic work, some of which direct participant observation of both professional stakeholders and residents. This paper largely focuses on the perspective of the professionals, since their actions affect the residents' lives later. The case studies are kept anonymous to facilitate an open discussion of values and issues found. Table 1 shows an overview of the cases studied. The number of units are given as a range in order to reduce identifiability. Each one of the projects was the first ZE refurbishment/building for the case study respondents. In that sense, they were all pilots, or Living Lab cases. 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 exactly the same way. They were accessed at different points in time and via different entry points (Table 1). The information on them is not complete but depended on the capacity of the researcher to access the context, as well as the capacity of those in the context to provide that access. It was easier to get access to construction company managers and housing corporation managers than to those of the manufacturers and service companies. The stakeholders interviewed or observed in this research were recruited serendipitously through events around a large research project in which the researcher was involved. For these events, construction companies and housing corporation building innovation managers were invited to contribute their perspectives. Subsequently to the events, the researcher asked the professionals whether they would be willing to share their stories for an academic publication. When they agreed, the stories they had told were selected for this paper and one or more follow-up interviews with them were held in order to deepen the findings. The aim of the analysis is not to present specific cases in their entirety, but rather to extract meaningful stories from them. The point is also not to *judge* whether particular actions were successful or not. The idea is to learn equally from all kinds of stories, to link the situations found to concepts from design thinking and to interpret them in new ways through this.

Table 1. Overview of the methods and cases studied. All cases concerned zero energy refurbishments or builds of social housing. Each one of the projects was the first ZE refurbishment/building for the case study respondents. The number of units are given as a range in order to reduce identifiability.

	Building	**Measures**	**Respondent**	**Study format**
Case 1	10-30 units multi-story social housing completed 3 years ago	ZE renovation. Insulation, triple glazing, heat pump, balanced heat recovery ventilation, solar panels	Client housing corporation building innovation manager. (HC project manager)	Structured group session with respondents Cases 1-3, 1.5 hr semi-structured online interview, project meetings
			Various construction company members (CC project managers): project manager social process, project manager onsite construction	Long term peripheral participant observation in project meetings, site visits
			Residents	In-home interviews
Case 2	50-100 units multi-story	ZE renovation. Insulation,	Project manager of the process design	Structured group session with

	social housing apartment building completed 6 months ago	triple glazing, heat pump, balanced heat recovery ventilation, battery, solar panels	research project (CO manager) connected to construction project	respondents Cases 1-3, 1.5 hr semi-structured online interview
Case 3	10-30 units social housing two-story single family dwellings completed 6 months ago	ZE new build following demolition, same residents. Insulation, triple glazing, heat pump, balanced heat recovery ventilation, solar panels	Housing corporation building innovation manager in charge of project (HC project manager)	Structured group session with respondents Cases 1-3, 1.5 hr semi-structured online interview
Case 4	250-300 units multi-story social housing apartment complex in preparation phase, demo unit done	ZE renovation. Insulation, triple glazing, heat pump, direct façade ventilation with central heat recovery extraction, battery, solar panels	Construction consortium project manager (CC project manager)	3 hr semi-structured interview onsite in demo unit
Not interviewed but featured via statements of other stakeholders: manufacturing company project manager (MC project manager), and service company project manager (SC project manager)				

3. Results

As we have seen, the outcome of a sustainable renovation can be termed a Product-Service-System (PSS) in that it fulfils several goals: use-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 results are structured into the *product* and the *use* part of the PSS and how they contribute to the *result.*

*3.1 How is the **produc**t in the PSS addressed in the cases in the design phase?*

The *product* in a ZE refurbishment 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, but also service touchpoints with the living arrangements of sitting residents and the service arrangements around them 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 is to standardise physical elements. In **Case 1**, the CC, MC and SC project managers together devised a set of installation boxes ('skids') (Figures 1a-d). The project partners had the ambition to make these boxes as small as possible in order to impact the building as little as possible, facilitate efficient maintenance and serialise the development for upscaling.

In Case 4, too, the CC and MC project managers developed new HV elements together specifically for the project at hand. In addition, they developed an app-based control system for the apartment that would enable the residents to control the temperature and other systems in the home, like lighting.

Another strategy 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, which made it possible to align the communication with the technical design. In Case 2, 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 the mutual expectations.

In Cases 1 and 4, and possibly also in Cases 2 and 3, the professionals realized a full scale, largely functional demo dwelling. A demo dwelling reveals how the components come together. Moreover, it is a cognitively accessible way to show residents what the plan is, and it is a persuasive demonstration of the construction company's competence in realizing the outcome. Yet these very qualities also carry a risk: construction professionals and residents alike can take them as the real thing, the specific solution, and do not see that they could still be changed. It is challenging for people to abstract from the concrete thing they see.

*3.2 How is the **use** in the PSS addressed in the cases in the design phase?*

The *use* in a ZE refurbishment 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?

Although the construction companies in Cases 1 and 4 created fully functional prototypes, demo dwellings, as mentioned in the previous section, they were not able to fully profit from them to anticipate on the future interactions the residents would have with their dwellings. In both of these cases, the entire process had a relatively short time frame, which affected the learnings from the demo dwellings.

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

In **Case 4**, due to the short time frame some aspects shown in the demo apartment were incomplete and preliminary instantiations of the concept, while appearing finished. The CC project managers 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 visible in the process. One pitfall to note is that the project managers' evaluation framework appeared incomplete. The prototypes differed in some respects from the way the technology would function in the house, but this was not made apparent. This meant that some resident reactions were in response to elements that were not final. The residents interpreted the prototypes as the definitive proposals and some confusion and uncertainty on the future use arose with the project stakeholders.

Cases 1 and 4 reveal a dilemma: the partners had great commitment to innovation but insufficient capacity to communicate about it and to implement the learnings on use from the prototypes within the short time they had available.

In Case 1, there were some uncertainties on the part of the CC and MC project managers on the residents' future interaction with the ventilation filters. Ventilation units have filters that have to be serviced by cleaning them every six to twelve weeks, depending on 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 installation box 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 a last step the CC project managers created a manual for the residents by combining the existing manuals of the separate technologies.

In **Case 2,** the CC project managers were in charge of both the technical design and the communication with the residents. The CC project managers had knowledge of design thinking processes and brought this thinking into the process. In their design, they located the HV technology close to the residents' living space and within reach, which made it well-aligned to their living practices. They engaged with expected use by producing a custom-made manual for the specific configuration of the refurbishment, in close collaboration with the manufacturers of the technologies and the residents themselves.

In **Case 3**, the HC project manager actively anticipated on the future behaviour 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: one, give residents control over their house via a control panel by the living room door to keep track of system functioning and energy use. Two, enable the HC to monitor the performance of the building services. Three, to streamline maintenance calls. After the residents moved in, project manager explained the operation of the systems to them verbally. They received no manual, since the system was expected to provide the guidance.

Design perspective. The examples have shown that the some of the professionals' considerations on future use 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. This suggests a counterintuitive conclusion in design terms. While no manual can compensate 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. In addition, both professionals and residents tended to take what was made at face value. It would be valuable to designate clearly in prototypes what is still open, and how certain elements of the product 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, the product development and prototyping processes could anticipate more on the use of the product and the values it embodies and iterate on it, for the benefit of the residents later. A greater diversity of purpose-specific prototypes might be more cost- and time efficient and more conducive to learning and optimizing of the product. In design, it is often assumed that prototypes should seem unfinished in order to not generate inaccurate expectations. Prototypes should be created with a specific evaluation goal in mind. A conceivable approach might be to create demo houses or demo situations where technology can be tested in an ongoing way.

3.3 Evaluating the product in use after the refurbishment/building completion

In the executed refurbishment projects, new insights emerged for the stakeholders when they entered the phase of use, the third component of the PSS ZE refurbishment. The second part of the results focuses on the phase after the refurbishment, when residents lived with the new technologies. Overall, the residents in the three executed cases 1-3 were very satisfied with the refurbishment/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. 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 many questions. Their difficulties with the systems persisted or new ones emerged over the months that followed. 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 of their commitment to make the building work. An issue that could not be resolved was that it proved to be physically impossible for some of the residents to clean the filters, and it was difficult 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 installation box as a confusing and unpleasant space that does not belong to their home space (Figure 1c). When opening the door to the box, residents were presented with a bewildering array of technology. Several of the residents applied an additional interpretation to the installation box, because it was located outside of their apartment: as a shed. There were some small spaces left over in the box, which some residents proceeded to fill with personal effects (Figure 1c). In one case, this resulted in severing a ventilation duct.

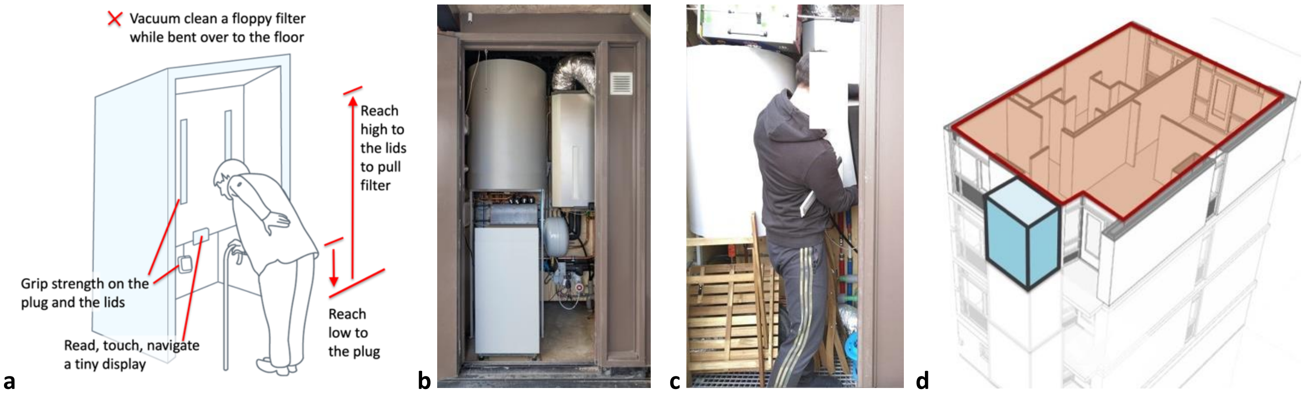

Figure 1a: unrealistic expectations put on a resident to maintenance a filter unit. **1b**: an installation box on the balcony, all installations combined in one space **1c**: the installation box being interpreted as a shed, and contorting the body in order to reach the filters for cleaning and not knowing where to leave the lid. **1d**: the installation box being interpreted as a space that does not belong to the home.

In **Case 2**, the HV 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 by placing 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 there was also a structure in place for personal contact. After the renovation, they CC project manager personally stayed engaged in any needed troubleshooting. The CC project managers also made arrangements with two residents who showed 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 was that all residents greatly appreciate that two residents have this social role. The intermediaries' approach was to welcome any comfort complaints from the residents in the period after the renovation and to 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 the personal contact with digital communication. The professionals were able to take away learnings for next iterations of the product.

In **Case 3** (new build single family dwellings), the HC project manager reported that the control panel 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. Still, the system had other benefits as well: in some cases, it was possible to respond to maintenance issues remotely before residents even noticed them, via resets. In addition, 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 direct the resident themselves do a minor repair or reset. However, there were resident complaints about too much automation and this continues to be tweaked, for example since it also extended to hallway lights. In addition, when the HC project manager visited the residents in an extensive evaluation round of 1.5hr 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 in the attic space (accessible via a permanent staircase), which raises questions 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 refurbishment. 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, that 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 HV 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 making primarily in terms of the things we provide, and not so much in terms of how people would interact with in an integrated way." The CC project manager expressed the desire to put in practice the valuable learnings gleaned through the demo house set-up.

Another set of issues arose after the completion of the refurbishment / build in **cases 1-3**. This pertained to the organisational use 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 both **Cases 1** and **3**, a resident had inadvertently deactivated a fuse, thus deactivating the gains from their allocated solar panels. In Case 2, the heating performance was lower than expected, requiring some error searching to fix it. In Case 3, a similar issue occurred with apparent excessive hot water use that turned out to be a reading error within the system.

During these 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 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, because 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.

Design perspective. The post-completion findings reveal a significant investment of energy of all involved. The phase provided many opportunities for reflective learning on the implemented PSS. The managers of the cases had underestimated the post-completion phase, the *use* part of the PSS. Time not spent in the design phase became time spent later. The complexity of a ZE PSS means that in-depth, contextual design and evaluation strategies are needed that cover all types of use. Such strategies should adopt a use-oriented perspective that engages with the situation of all users, the organizational users and the residents with the meanings they bring to their homes. The value lies in a more reliable prediction of resident satisfaction and energy efficiency, since residents would be better able to engage with the HV technology. The project managers of all partners proved to be very resilient and resourceful in the face of some of the unexpected pitfalls they encountered. Yet while they possibly currently operate partly out of idealism, it seems like manufacturers, service partners and construction companies currently do not have sufficient business models for the phase after completion. One HC project manager created their own business model for this phase. There is space for new business models to capture the post-completion learnings. Another possibility would be to abstract the findings beyond the specific, concrete product that has been implemented, so that the more generalized findings can then provide input for new processes starting up. Such input could for example be standardized in new regulations.

4. Discussion

With regard to the questions what are the situations for professionals in trying to make ZE refurbishments or builds of social housing work, and how do design notions provide possible paths to co-learning processes that also include tenants' experiences, the results have shown the *use* part provides many insights. The situations of professionals in making ZE refurbishments or builds of social housing work extended significantly in the cases studied 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. While the renovations in cases 1-3 were successful overall and the residents satisfied with the results, some of the residents' disappointments with their interaction with the HV technology, if scaled up, would have the potential to inhibit rather than accelerate uptake and make it more difficult to gain the consent of residents in the future. In addition, the amount of effort that the professionals now put into post-renovation tweaks does not seem scalable. All of the professionals in the cases had the goal of serializing and industrializing the proposals for upscaling. There is always urgency. With every development, the professionals are focused on the concrete thing they are developing and the technical challenges of realizing it. A contribution that design research can make is that new proposals, new products can be framed in terms of interactions. Studying the residents' post-refurbishment/build situation closely revealed relevant situations and insights that could have been addressed earlier in the process. The benefit of early involvement is that it elicits knowledge on whether residents are enabled to convert the resource ZE housing into a functioning that fulfils their needs (Heylighen & Bianchin, 2018) and who is included in and excluded from using the design. From a design perspective, is it possible to prototype and evaluate the technology measures in advance, create more certainty, and with enough time available, iterate on them to fulfil needs better and save time later. That way, efficiency can be gained, new directions can be discovered, and transferable learnings generated.

The results have shown the relevance of eliciting the residents' perspective and experiences. Communication technology was shown to be a valuable tool to scale up their involvement early on in a project. By taking the situations in the field as the point of departure, we have identified further co-learning opportunities that are close to the practices in the field and could answer the calls of Baborska-Narożny & Stevenson (2019) and Bridi et al (2022) for such techniques. They opportunities we identified include using demo dwellings more for design and iteration, and to design these demos themselves more iteratively so that well-defined use issues can be studied. 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. Hyysalo et al (2007) already discussed how users often shape technologies through use and appropriation, regardless of their technical understanding. With a more participatory sociotechnical approach, issues relating to usability and the meanings of technologies and homes for residents could have been addressed. 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.

One might also question whether in the interest of energy efficiency, professionals are too quick to accept a reduced view of what it means to be a human in a space or environment. Or in the terminology of Ceschin & Gaziulusoy (2019), whether the design of human interactions with elements of their environment need all be seen as technic-centred. The interactions of residents with their homes take place on the level of user-product interaction, yet cannot be framed as a technocentric problem. Rather, it is also at the micro-level of interactions at which societal issues such as inclusion or exclusion manifest. Through these case studies, albeit incompletely and anecdotally, we have compared the effectiveness of ZE refurbishment/build designs and found that greater involvement of tenants leads to more successful results.

We have also found that the "middle actors" (Reindl, 2020) face significant challenges in aligning their consortia in such a way that they have control and overview of the result. They could benefit from more sharing of experiences in order to be able to learn about the pitfalls and potential benefits faster. This could take the shape of fora and workshops to exchange experiences.

4.1 Limitations

This research has provided particularly many findings in the *use* part of ZE refurbishment/builds viewed as PSS, as opposed to the other parts *result* and *product* (Gaziulusoy, 2015), although they are of course all connected. This could be in part due to bias of the researcher on the topic. However, the use part is generally of lower interest in the field, since the bulk of the stakeholders' activities lie in the design and planning phase (Konstantinou et al, 2022). A design perspective can help balance this better. However, a limitation may be that the proposed activities require skills in engaging with non-professional voices that may not all be present in the field and difficult to integrate in the sets of disciplines that pervade in it (Janda & Parag, 2013). Dialogues are a topic of design in themselves (Roosen et al, 2020). The cases we have studied may or may not have been typical of the process of ZE refurbishment/builds. 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 for comparability (Graneheim & Lundmann, 2004). A valuable component of future research in this vein would be to highlight more of the perspective of residents and of the quality of the dwellings for them, for example by combining the research approach with Post Occupancy Evaluation (Guerra-Santin & Tweed, 2015).

5. Conclusions

This paper has employed case studies to study the reality of sustainable renovation processes. We saw that while most things go smoothly and turn out satisfactory for tenants, some do less so. By drawing on theory from sociotechnical, participatory and inclusive design, we have added new perspectives on the situations in the field and have proposed techniques that could address the issues that were identified. These techniques promote both collaboration of the stakeholders in the field as well as tenant involvement, so that tenants can exert sociotechnical influence on sustainable renovation processes and outcomes.

It would be desirable to make it easier for the professional stakeholders in the field to manage sustainable renovations, because of the urgency of the energy transition that all parties are aware of. It is probably frustrating for them to be aware of the urgency, yet so pressed for time and resources that some outcomes are not entirely as desired. This can in turn cause failure costs and dissatisfactions that need to be tackled – in other words, slowing processes down rather than speeding them up. This could be addressed by creating spaces for learning and iteration such as demo dwellings and concepts of future interaction and use of the PSS of ZE refurbishment/build. This paper has shown that creating more iterative and evaluative strategies for the field has the potential of enabling the energy transition to speed up.

Acknowledgements
This project is executed with the support of the MMIP 3&4 grant from the Netherlands Ministry of Economic Affairs & Climate Policy as well as the Ministry of the Interior and Kingdom Relations. This study has been developed as part of the Integrale Energietransitie in Bestaande Bouw (IEBB) Theme 2 - Data-driven Optimization of Renovation Concepts project. The project is a multi-year, multi-stakeholder program focused on developing affordable and user- friendly renovation concepts for residential buildings.

There are no **conflicts 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. DOI: 10.1080/09613218.2018.1501535

Bervall-Kåreborn, B. and Ståhlbrost, A. (2008). Participatory design: one step back or two steps forward?. In Proceedings of the 10th Participatory Design Conference, 102-111. Indiana University.

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

Blomberg, J. and Karasti, H. (2012). Positioning ethnography within participatory design. Routledge international handbook of participatory design, 86-116.

Boess, S., Silvester, S., De Wal, E., & De Wal, O. (2018, August). Acting from a participatory attitude in a networked collaboration. In *Proceedings of the 15th Participatory Design Conference: Short Papers, Situated Actions, Workshops and Tutorial-Volume 2* (pp. 1-6).

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), 2595.

Ceschin, F., & Gaziulusoy, İ. (2019). *Design for sustainability: a multi-level framework from products to socio-technical systems*. Taylor & Francis. DOI 10.4324/9780429456510

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, November 28). *2050 long-term strategy, Vision for a long-erm EU strategy for reducing greenhouse gas emissions.* Climate Action. Retrieved March 5, 2022, from https://ec.europa.eu/clima/eu-action/climate-strategies-targets/2050-long-term-strategy_en

Gaziulusoy, A. I. (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

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

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

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.

Hyysalo, S., Johnson, M., & Heiskanen, E. (2007). Guest Editors Introduction: Design-Use Relationships in Sociotechnical Change. *Human Technology: An Interdisciplinary Journal on Humans in ICT Environments*.

Janda, K. B. & Killip, G. (2013). Building expertise: Renovation as professional innovation. In R. L. Henn and A. J. Hoffman (Eds.) *Constructing green: The social structures of sustainability*, MIT Press, 35-55. DOI: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, DOI: 10.1080/09613218.2013.743396

Keyson, D. V., Guerra-Santin, O., & Lockton, D. (2017). Living Labs. *Design and Assessment of Sustainable Living. Netherlands: 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.

Konstantinou, T., & Heesbeen, C. (2022). Industrialized renovation of the building envelope: Realizing the potential to decarbonize the European building stock. In *Rethinking Building Skins* (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), 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*, 101391.

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

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*, 110102.

Pihl, D. (2019). *The Making of an Energy Renovation: Knowing & Acting on Energy-Saving Features through Design Processes*. Aalborg Universitetsforlag. PhD Series, Technical Faculty of IT and Design, Aalborg University

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).

Schön, D. A. (1983) *The Reflective Practitioner: how professionals think in action* London: Temple Smith.

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

Suchman, L. (1987). *Plans and situated actions : The Problem of Human-Machine Communication.* Cambridge University Press, New York.

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. Springer Nature Switzerland AG. In Vezzoli, C., Garcia Parra, B., & Kohtala, C. (Eds.) *Designing Sustainability for All: The Design of Sustainable Product-Service Systems Applied to Distributed Economies*. Springer Nature.

Wade, F., & Visscher, H. (2021). Retrofit at scale: accelerating capabilities for domestic building stocks. *Buildings and Cities*, *2*(1), 800–811. DOI: http://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*. https://doi.org/10.1016/j.enbenv.2021.06.002