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Zero Energy Renovation: How to Get Users Involved?

Editors

Tineke van der Schoor and Fred Sanders

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Zero Energy Renovation: How to Get Users Involved?

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Editorial

Challenges of Energy Renovation

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Abstract
One of the most complex and urgent challenges in the energy transition is the large-scale refurbishment of the existing housing stock in the built environment. In order to comply with the goals of the Paris convention, the aim is to live "energy-neutral,'' that is, a dwelling should produce as much sustainable energy as it consumes on a yearly basis. This means that millions of existing houses need to undergo a radical energy retrofit. In the next 30 years, all dwellings should be upgraded to nearly zero-energy buildings, which is a challenge to accomplish for a reasonable price. Across the EU, many projects have developed successful approaches to the improvement of building technologies and processes, as well a better involvement of citizens. It is important to compare and contrast such approaches and disseminate lessons learned. In practice, it is crucial to raise the level of participation of inhabitants in neighborhood renovation activities. Therefore, the central question of this issue is: How can we increase the involvement of tenants and homeowners into this radical energy renovation?

Keywords
local energy policy; (near) zero-energy renovation; owner-occupied dwellings; participation; renewable energy strategy; social housing; user behaviour; user satisfaction

Issue
This editorial 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. The Challenge of Accelerating the Energy Transition

The energy renovation of the existing housing stock is one of the most difficult tasks in the energy transition, not only because energy renovation is radical in a technical sense, but also because homeowners and residents must be willing to cooperate and need to accept the renovation in the usage situation. Convinced that sharing knowledge and experiences is important to support this transition, it is with great pleasure that we as editors have put together an issue on energy renovation. We are delighted that so many researchers were willing to share their results with us in this thematic issue.

Many of the contributions submitted address the behavioural factor of residents for the success of the transition. Here, we quote climate psychologist Dr. G. de Vries:

> We know that the climate is changing because of human behaviour, so we could also have a positive effect on climate change, through green behaviour, for example. This is not just behaviour by ordinary citizens, but also governmental bodies, politicians, businesses, science and the media. These factors also influence each other: journalists can initiate a social debate, the government can direct behaviour through policy and citizens in turn can influence the political agenda. I find the interaction between all these players fascinating, particularly as this is a topic that affects us all. (de Vries in TU Delft, n.d., para. 1)

Furthermore, she argues that:

> Besides a psychological angle, behavioural change also has technological, financial and administrative

> aspects. If you want to make the energy supply green, it not only has to be technically and financially feasible, you must also have the support of politicians and citizens. If citizens are not enthusiastic about carbon storage or geothermal energy, or if they want a solution that will be very expensive, the chance of success is small. (de Vries in TU Delft, n.d., para. 3)

As editors we can endorse these statements from our own research. From her research in sustainable citizens' initiatives, Tineke van der Schoor knows how important it is for citizens that initiatives are taken by someone who can be trusted, with an organizational structure that offers opportunities to participate (van der Schoor et al., 2021). Research by Fred Sanders shows that for sustainable initiatives, the interaction between government, experts, and citizens, whether or not they are formally organized, determines the results. We learn from this research that the sustainable energy transition is an enormous operation where good preparation is decisive for the success that can be achieved (Sanders & de Oliveira, 2020). For this, it is necessary to be open to the knowledge of others, which formed the basis for this thematic issue.

2. A Diversity of Scientific Contributions

The theme of (near) zero energy renovation is topical and has attracted the attention of scientific researchers as evidenced by the 10 articles included in this thematic issue. Three articles are based on research in New Zealand, Estonia, and Belgium respectively, one article compares approaches in France and the Netherlands, and one article is a review focused on the EU; the remaining five articles are focused on the Netherlands. This means that this thematic issue can be valuable for a broad range of researchers and practitioners in the building sector, thus achieving an important objective of this issue.

Based on the invitation for this thematic issue, the articles can be given a place in the diagram in Figure 1, according to their starting position. We position the articles on two axes: case studies versus theory development, and user behaviour versus technological solutions.

In this diagram, we identify two dimensions. The first dimension concerns the empirical–theoretical axis. All articles emphasizing empirical research describe case studies. However, some articles also aim to contribute to theoretical approaches of energy renovation. The second dimension is about the technological–behavioural axis. Although the majority of the articles present studies of user behaviour, two articles take technological developments as their starting point.

With pleasure, we present the following 10 articles to the readers:

1. Pellegrino et al. (2022): Comparison of energy renovation projects in France and in the Netherlands; findings include that the urgency of the goal of achieving a massive reduction in energy consumption sometimes leads to a lack of attention to residents' interests. A plea to pay more attention to the behaviour of residents in connection to energy renovation projects.
2. Mooses et al. (2022): Research carried out in Estonia after residents' acceptance of smart

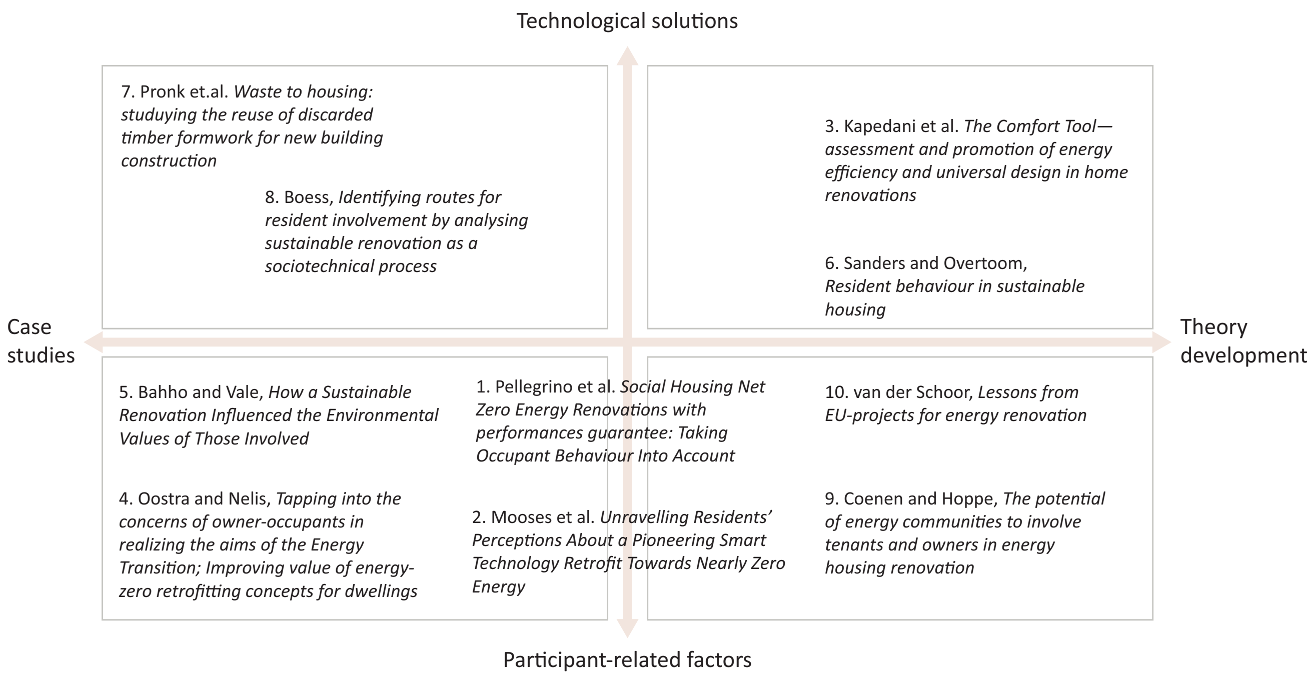

Figure 1. Diagram positioning the articles on two axes: Case studies versus theory development, and resident behaviour versus technological solutions.

technology when renovating their homes. The article shows that residents interested in the technical interventions are less critical of the results than residents primarily concerned about climate change.
3. Kapedani et al. (2022): Research in Belgium and the EU focused on comfort as a factor that makes residents accept sustainable housing; a "comfort tool" is developed and tested in renovations.
4. Oostra and Nelis (2022): Here, a framework is developed to match the interests of renovation contractors and resident values, to make choices for retrofit sustainable housing renovation.
5. Bahho and Vale (2022): The renovation of a log cabin (in New Zealand) proved that a sustainable retrofit influenced the values of the people related to the project.
6. Sanders and Overtoom (2022): Based on grey data from the construction sector enriched by university researchers, action perspectives are identified to handle resident behaviour for sustainable housing construction in the Netherlands.
7. Pronk et al. (2022): Experiences with a house construction (in the Netherlands) by reusing demolition building materials were enriched with other project results, added with socio-economic motivation insights.
8. Boess (2022): Sustainable renovation processes are both technological and social, and for success both have to be detected and taken into account in involving residents, as found in case studies in the Netherlands.
9. Coenen and Hoppe (2022): Renewable energy communities can help to involve tenants and owners in energy renovation projects, based on empirical data from the H2020-project Rescoop.
10. van der Schoor (2022): It is argued that it is important to increase collaboration on the supply-side, for example by One-Stop-Shops. Furthermore, this would also help to simplify the renovation process for customers.

Starting from the diagram for positioning each of these scientific contributions to the field of knowledge determined by the two axes, the recurring message in most of these contributions is that the actors involved have outdated images of each other. The building sector, designers and contractors in particular, appears to be still too far removed from the transition process, as a result of which they act in a passive manner, while the innovation and associated renewal of the products offered for construction and renovation must arise from this sector. On the other hand, citizens are in need of easy to understand technical and financial information on energy renovation to support them in renovation decisions. The lack of such accessible information is one of the factors causing the slow progress of the energy transition in the built environment. European and other governments strive to make progress in the energy transition but forget that they are dependent on the actions of citizens and the building sector. Collaboration is therefore needed and this requires the exchange of knowledge, to which this thematic issue aims to make a modest contribution.

Given that the articles are mainly based on case studies, it is inevitable that conclusions are difficult to generalize; they apply for a certain target group, for a type of projects, or for homes in specific price categories. On the other hand, in many of the articles it is emphasised that residents should be more involved in sustainable renovation projects and that software and other tools have been developed to use them. It remains challenging to provide clear advice tailored to different situations, while the time pressure for a zero-government housing sector within the EU is increasing further, due to the still increasing CO_2 emissions.

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Conflict of Interests

The authors declare no conflict of interests.

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Tineke van der Schoor is a senior researcher at the Research Centre for Built Environment NoorderRuimte of the Hanze University of Applied Sciences, Groningen, the Netherlands. Her research focus is the energy transition in the built environment, including energy renovation, historical buildings, and community energy initiatives. Currently, Tineke is investigating how citizens' initiatives can contribute to the heating transition. Furthermore, she is interested in the expanding roles of community energy initiatives in the governance of the energy system.

Fred Sanders recently graduated from the Department of Urbanism at TU Delft with his research on bottom-up resident initiatives for creating sustainable cities. He holds an MSc in civil coastal engineering and an MBA from the Erasmus University of Rotterdam. He has twenty years of experience in real estate management and public administration. He is a keynote speaker, journal editor, columnist, and writer of youth novels, promoting sustainable and resilient initiatives.

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Article

Social Housing Net-Zero Energy Renovations With Energy Performance Contract: Incorporating Occupants' Behaviour

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Abstract
This article examines how the behaviour of occupants is assessed in a project with ambitious targets for energy use reductions and within the framework of an approach based on an energy performance contract. Its starting point is the observation that there may be significant disparities between the consumption threshold required by the regulations or the labels and the actual building consumption in its post-delivery existence. While behaviour cannot be the only factor explaining this overconsumption, the promoters of high-performance renovation operations often marginalise their importance. The recent surge in requirements for energy consumption reductions in new or renovated buildings in Europe further exacerbates these problems. In light of these challenges, there is a strong demand for compulsory verification of post-delivery performances and for developing energy performance contracts. In this context, the behaviour of a building's occupants can no longer be considered as a simple adjustment variable. Through the analysis of Energiesprong, a net-zero energy renovation approach for the social housing developed in the Netherlands and in France, built around the principle of an energy performance contract over a long timeframe, the article highlights the injunctions to behavioural changes, the strategies, the negotiations, and the adjustments deployed by the project leaders. It finally shows that there is still a long way to go before the occupant's behaviour in a high-energy performance renovation project is fully taken into account.

Keywords
Energiesprong; energy performance contract; France; net-zero energy renovation; occupant behaviour; social housing; the Netherlands

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

At a time when concerns associated with climate change and the depletion of various kinds of resources are increasingly acute, we are seeing an acceleration in the implementation of policies on the ecological transition in Europe. Reducing the consumption of carbon energy, especially in the buildings sector, is one of the primary goals (Rosenow et al., 2017). The main measures consist of fixing performance obligations and maximum permitted energy consumption thresholds relating to the field of application of thermal regulations. Generally, conformity with these objectives has to be demonstrated in the design phase through studies and simulations and is only very rarely verified from actual consumption data captured after delivery, when the building is already in use.

However, numerous reports and studies (Branco et al., 2004; Santin et al., 2009) have revealed that there may be significant disparities between the consumption threshold required by the regulations or the label and the actual consumption of the building in its post-delivery existence. These disparities can be explained by various factors occurring during the design, the construction, and the post-delivery phases. Among all factors, occupants' behaviour seems to play a significant role (Gram-Hanssen & Georg, 2018).

These disparities in consumption can be very problematic for the owners and/or the occupants of the buildings, who may find themselves facing higher energy bills than expected. The recent surge in requirements for energy consumption reductions in new or renovated buildings in Europe further exacerbates these problems. Very ambitious approaches that aim to achieve energy neutrality are emerging. Although not yet compulsory, post-delivery verification of actual consumption is increasingly included as part of high-quality labelling and certification procedures. In the light of these challenges, we are seeing strong demand on the part of building owners, supported by the regulatory authorities, for the development of a guarantee of real performances (Zou et al., 2018), such as energy performance contracts (EPCs). These aim to provide contractual security and guarantees regarding reductions in the energy consumption of a building or stock of buildings, consumption that is verified and measured over time (Shang et al., 2017).

In this context of compulsory verification of results and performance guarantees, the behaviour of a building's occupants becomes even more important. It seems essential to incorporate and understand it at a fine-grained level for a finished project to conform to expectations with regard to lower energy consumption (Jain et al., 2017; Lu et al., 2017). That, at least, is the argument of this article, which raises the following research questions: (a) How does a project with ambitious targets for reductions in energy use coupled with EPC assess occupant behaviour? and (b) what consequences and impacts do these types of projects have on the occupants?

In order to tackle these questions, we studied the EnergieSprong approach (Box 1), a procedure that proposes a very high-performance energy renovation standard, such as net-zero energy (NZE) aiming to refurbish a building or a cluster of buildings to achieve a zero balance between energy consumed and energy produced from renewable sources, and is built around the principle of a guarantee of neutral energy performance over a long timeframe (25–30 years). Studying how occupants' behaviour is accounted for in this kind of innovation system seems particularly useful to us because the efforts needed to make a building energy-neutral require profound alterations to inhabited space, alterations that also demand changes in behaviour.

In the last few years, the scientific literature has become interested in the Energiesprong approach. Studies have emerged, mainly from Dutch and English researchers. These studies are mainly concerned with understanding the economic model of Energiesprong in connection with national regulatory tools, by analysing the costs and the number of renovations carried out (Visscher, 2017), the role of intermediary actors (Brown et al., 2019; Sovacool et al., 2020), or the EPC (van Hal et al., 2018). The industrial aspect of the process is also fairly studied (Micelli & Mangialardo, 2017). Some studies focus on transfer to other countries and the feasibility of adapting the Energiesprong model (for the United States, see Egerter & Campbell, 2020). In France, a study illustrates the innovations and transformations for the professions and the actuator systems involved (Pellegrino, 2019). Fewer studies are interested in the role played by occupants' behaviour in Energiesprong or, broadly, in NZE renovations (van der Schoor, 2020; van Oorschot et al., 2016; Wekker, 2020).

As part of this research, we aim to shed light on this less covered aspect of the Energiesprong approach. We adopted a socio-technical perspective. The aim is to go beyond, on the one hand, techno-centric approaches, which reduce the behaviour of occupants to a few standardized socio-demographic variables, and, on the other hand, studies from economics and environmental psychology, which, by focusing on the individuals' orientations, can fail to examine the influence of context on energy-related behaviours (Bourgeois et al., 2017). From this socio-technical perspective, we decided not to directly investigate occupants' behaviour, examine technical systems in the renovated houses, or undertake a measurement campaign to quantify energy consumption. Instead, we apprehended Energiesprong NZE renovation projects with energy performance contracting procedures as a process anchored in space and time, involving numerous stakeholders, including the establishment of protocols and forms of contract and a massive recourse to technical equipment, systems, and technologies, and we investigated how occupants' behaviour is assessed in the different stages of a project. In order to

Box 1. Short presentation of Energiesprong.

Energiesprong was born in 2010, in the Netherlands, and aims at scaling up NZE (*nul op de meter* in Dutch) renovations, developing the industrialization of buildings' processes (Figure 1), starting from the social housing sector. The implementation of a set of innovations (contractual, organisational, regulatory, technical, and financial) initially focused on the renovation of social housing and has enabled the social landlords to launch a renovation plan over an extended period and on a large scale, which has had the effect of halving the price of a home renovation (Oostra, 2017). Beyond the Netherlands, the approach is now being applied in the United Kingdom, France, Italy, the United States, and Germany, among others. In France, although still at an experimental stage, it appears to be gaining ground. A charter supporting Energiesprong was signed in 2017, involving 111 partners, including 14 social housing landlords, with a commitment to undertake 3,600 renovations before 2022. At the time of writing (January 2022), 6,316 renovations, in progress or completed, are listed on the Energiesprong website.

Figure 1. A prefabricated facade for a renovated house in Wattrelos.

do that, we have mobilized a large body of literature. In this corpus, three areas of study seem particularly relevant for our study: The first one explores domestic energy behaviour (Frederiks et al., 2015; Lutzenhiser & Gossard, 2000; Steemers & Yun, 2009) and, specifically, in relation to the use of new technologies and the materiality of the domestic space (Shove, 2003; Stephenson et al., 2010); the second one focuses on high-performance energy renovation projects (Gianfrate et al., 2017; Gupta & Gregg, 2016); and the last one is dedicated to the comprehension of the "energy performance gap" (Gram-Hanssen & Georg, 2018; McElroy & Rosenow, 2019; Topouzi et al., 2019; Zou et al., 2018) and of the procedures designed to deal with it, such as the EPCs (Jain et al., 2017; Lu et al., 2017; Zhang & Yuan, 2019). The analysis of literature on EPC reveals a paucity of studies, putting this contracting form in perspective with the behaviour of the occupants by illustrating the impacts that it can have on the latter, which is the perspective adopted by our study.

In Section 2, we describe the methodology and the case studies. Section 3 presents the results of the research. In the first place, we describe how the stakeholders (building owner and members of the project consortium) in the Energiesprong approach in France and the Netherlands tried to incorporate the behaviours of building occupants in the different stages of the renovation project. Secondly, we focus on the performance gap and on the questions raised by the EPC. These findings will then be discussed and assessed in Section 4.

2. Methodology

As part of a larger project that encompasses multiple research pathways, we analysed Energiesprong NZE renovation in the Netherlands and in France in its principal field of application: social housing. The choice to study Energiesprong in the Netherlands depends on the fact that, since the Dutch experience predates that of the other countries, it provides finer-grained material and allows going further in the study of the post-delivery phase. In the context of this article, we will also rely on the study of two Energiesprong projects in France. Although too recent to allow for post-delivery feedback, these French projects will contribute further material to the analysis of pre-project and construction phases and by showing a different operational and economic model.

From the very beginning of the research the centrality of the EPC appeared, raising questions concerning the challenges and the consequences that it generates. This led us to dedicate part of the interview time to dealing with the EPC and, in particular, with the place given to occupants' behaviour in this procedure. The present analysis relies on 25 interviews carried out with social landlords, associations of social landlords, constructors and associations of constructors, technical engineering offices, intermediate contractors, and local public authorities (Table 1). Semi-structured interviews were carried out based on a protocol composed of two parts. The first one is common to all the interviews and focuses on the role and the interests of the person and the represented structure in the Energiesprong approach. The second part is specific to the type of actors interviewed. The topic of the EPC integrating occupants' behaviour was discussed with all the actors by adapting the exchanges to the role they cover in the procedure. Finally, some other questions were adapted to the field of study. As the Dutch projects are older, the interview focused more on feedback. In France, it is rather the adaptation of the model, in particular economic, which was questioned.

We specifically interviewed stakeholders who have been or are engaged in an Energiesprong energy renovation projects in two municipalities in the Netherlands (one project in Stadskanaal and three projects in Leeuwarden, that we were also able to visit in June 2021;

Table 1. Body of interviews used for this article.

	Case study localisation	Project data	Type of stakeholder	Position of the respondents	Date of interview
The Netherlands	Stadskanaal	2018–2020; 183 individual houses	Construction company	1. Customer and market project manager, 2. Energy and technology officer	12/05/2021
			Architecture office	Project manager	06/06/2021
			Social landlord	Housing portfolio manager	19/05/2021
			Local public authority	Energy and housing officer	01/06/2021
	Loppersum	2017–2019; 173 individual houses	Social landlord	Property manager	07/06/2021
	Leeuwarden	2017–2021; three projects, same landlord and constructor; 118 + 132 + 55 individual houses; 84 dwellings	Social landlord	Property manager	09/06/2021
			Local public authority	Sustainable development policy advisor	17/05/2021
			Construction company	Innovation manager	12/07/2021
			Energy supplier	Strategy and innovation consultant	30/06/2021
			Architecture office	Project manager	08/06/2021
	National level	—	Intermediate contractor	Sustainability, circular economy, and scale-up project manager	03/05/2021
			Researcher	Doctor of architecture and building environment	17/03/2021
			Researcher	Senior researcher at the built environment research center	16/03/2021
			Association of construction companies	Director of energy transition program	14/07/2021
France	Pays de la Loire	2021–2024; four projects, association of landlords; 2,000 individual houses	Social landlord association	Director	07/05/2021
			Technical engineering firm	Director of development	10/06/2021
			Association of construction companies	Director	07/05/2021
			Local public authority	Deputy director of energy and environmental transition	04/06/2021
	Wattrelos	2021–2022; 160 individual houses	Social landlord	Operational activity manager	28/04/2021
			Architecture office	Project manager	07/04/2021
			Construction company	Site manager	17/05/2021
			Technical engineering firm	Research department manager	27/04/2021
			Local public authority	Manager of town planning and building permits	06/05/2021
	National level	—	Intermediate contractor	Energy market and territories director	14/04/2021
			Energy supplier	1. Regional director, 2. Assistant delegate connection, 3. Large project and smart grid manager	04/06/2021

Note: Anonymity required by stakeholders.

we also wanted to study Loppersum project, but only the social landlord accepted to be interviewed) and some French municipalities (Wattrelos, visited in May 2021, and different municipalities in the Pays de la Loire region involved in one common large project).

The paucity of existing projects explains the choice of the French case studies. The very first pilot projects, in the towns of Hem and Longueau, have a limited scale (10 and 12 individual houses) and have been studied elsewhere (Pellegrino, 2019). The Wattrelos project (160 houses) is the first large-scale Energiesprong project in France, followed in chronological order by a similarly large project in Pays de la Loire. Other ongoing projects are too recent to supply materials for analysis. Regarding the choice of case studies in the Netherlands, we first made a table listing all the Energiesprong projects in the Netherlands, drawing on Projecten—Energielinq (https://stroomversnelling.nl). We analysed this corpus through several filters: the size of the operations, the landlords with the greatest number of projects, and the construction companies involved. After combining these criteria, we chose two contrasting case studies: the Stadskanaal project and the Leeuwarden project, the former involving prominent and very active actors in Energisprong and the latter, in contrast, involving actors with little experience in this type of project.

Beyond the interviews, additional materials included a large body of literature as well as numerous regulatory texts, documents based on communication around pilot projects, or else project specifications.

3. Results

3.1. Inform, Convince, and Constrain in a Standard: The Three Facets of Taking Occupants' Behaviour Into Account

In this part, we show that building owners, architects, and construction firms had not anticipated and, consequently, struggled to understand that the success of the NZE approach heavily depends on the occupants' motivation and ability to change their behaviours. In other words, the role of occupants' behaviour in this process has been underplayed.

3.1.1. The Pre-Project Phase: Making People Accept the Approach at All Costs

It would seem essential to the success of the Energiesprong renovation, the purpose of which is summed up in a set of specifications (Box 2) and in which the use of energy is fundamental, that the inhabitants of Energiesprong projects should understand and accept it.

In fact, the need to obtain prior approval for the renovation projects from 70% of tenants in the Netherlands and from 50% in France complicates the task for building owners (Figure 2). In addition, the consumption and performance data of the renovated building have to be monitored in order to check that the NZE target is met, which requires the prior consent of the residents for these data to be used (this data collection process has to comply with the General Data Protection Regulation). In this very tricky phase, the landlords organise discussion meetings with residents in order to demonstrate the day-to-day benefits of Energiesprong and to address their questions and concerns (Woonwaard & BAM, 2016). A mismatch between the expectations of landlords and of residents can be found. While the primary goal for the landlord and the project consortium is energy neutrality, in most cases the priority for tenants is improving comfort and aesthetics, explains one Dutch landlord: "'I've got a lovely kitchen. I've got a nice bathroom. My toilet looks good.' Nobody talks about: 'I have an energy bill of zero'" (Landlord 1, interview, 2021). As a number of landlords explain, the concept of energy neutrality is not very obvious or very exciting for residents, since the savings on energy bills are only visible after a year of residence in the renovated space.

Similarly, while the most significant changes in terms of technical systems—the main topic of discussion and

Box 2. Energiesprong specifications.

Energiesprong projects are required to meet a particular set of specifications:

- The temperature within the home must be 21°C and not exceed 25°C for more than 10% of the year.
- The interior air quality and ventilation that is comfortable for occupants must be maintained at fixed levels.
- Domestic hot water consumption must remain below a certain threshold.
- The energy requirement of the dwelling must be below 25 kWhPE/m²/year, with the implementation of a performance guarantee regarding a real overall energy balance capped at 60 kWh/m²/year.
- The renewable energy produced must be at least equal to the consumption requirements (energy neutrality).
- Monitoring of the consumption and energy performance of housing units is required in order to meet the NZE target.
- The NZE target must be guaranteed every year in accordance with a standard situation based on "normal conditions of occupation" defined during the design of the project.

Source: Energiesprong (2021).

Figure 2. Stadskanaal. On the right, we can see a resident is in his garden, satisfied with his new house. On the left and in other houses of the district the renovation project did not take place because the residents were opposed to it.

innovation for the project consortium—are the installation of photovoltaic panels, a heat pump, and an external plant room (Figure 3) to manage the operation of the building's energy system and mechanical ventilation system, the residents are more interested in very practical and much less structural questions, such as the electric hob that replaces their gas cooker. This is in fact the issue around which opposition tends to crystallise, as one French design office project manager told us: "Removing their gas, that's also something that is difficult to explain to people" (Member of technical engineering firm 1). Some landlords even end up covering the costs associated with ditching gas, which is a change that can also put people off the project, in particular the need to acquire a whole new set of appropriate saucepans and frying pans.

Figure 3. External plant room installed in the garden in Hem (France) and Stadskanaal (Netherlands).

These two examples show how, in the pre-project phase, building owners and residents perceive the renovation project in different ways. The NZE concept remains an abstract one for the occupants, who are more interested in improvements in appearance and comfort. It should also be stressed that in this pre-project phase, most of the landlords interviewed, especially in the Netherlands, chose not to spend too much time talking about the significant behavioural changes that the new technical objects and systems (photovoltaic panels, heat pump, ventilation system, etc.) will require. As we will see, this choice, made in order not to frighten tenants and to persuade them to go along with the project, will have serious repercussions after delivery when tenants begin to experience the impact of the changes caused by the renovation.

3.1.2. Construction: Renovation Timespan and Work on an Occupied Site

In the Energiesprong specifications, the renovation work is carried out while the site is occupied and must be completed as quickly as possible: two weeks per dwelling, including a maximum of one week inside the house itself in order to limit the inconvenience for tenants. While the two-week limit for the work is usually respected, which is a noteworthy improvement on traditional renovation processes, the tenants will, in fact, be inconvenienced over a much longer period, notably because of the need to upgrade or remake the utility networks (electricity, gas, and fibre; Figure 4). In addition, work will continue across the neighbourhood as a whole for several months, which prompted this remark by the project representative of a design office working with a French consortium: "To say that it's only 15 days of renovation work for the tenants is somewhat sugar-coating the pill" (Member of technical engineering firm 2). From the point of view of the occupants, this way of working has the advantage that they do not have to move out while the renovation is underway. In the Netherlands, a communal house may be set up in the neighbourhood where tenants can rest, have a shower, or cook on days when the water and electricity are cut off in their homes.

On the other hand, managing the work is particularly difficult because the scale of the project (several hundred houses renovated at the same time) means that there is a wide variety of family and social arrangements, to which the construction firms and subcontractors have to adapt. An energy and technology manager of a Dutch construction firm explains:

> When you renovate 10 houses, you get 10 kinds of people. We have old people who need care. We got young people [who] go to school and need to study at home or do homework. We got people who are on holiday and don't want to give us the keys of the house. (Manager of construction firm 1)

While some companies apply the learning by doing and treat this complexity as an opportunity to develop the business and their skills in working on an occupied site, others fail to cope with the challenge. As a result, the quality of the work and the relationship with tenants are compromised, and the landlord and contractors tend to blame each other for the failure (interview with the project representative of a Dutch construction firm). In addition, our interviews reveal the lack of foresight, on the part of both the landlords and the occupants themselves, about the upheaval produced by the speed of the spatial changes during the work: "At certain point when

Figure 4. Public space affected by energy network upgrade in Wattrelos.

you're sitting in your living room you didn't have a window behind you anymore. At the front, you could walk straight out from your living room" (Landlord 1). A French landlord and constructor share the same feedback. It is at this point that the tenants become aware of the scale of the changes caused by the renovation to the space where they are living.

3.1.3. After Delivery: A Normative Approach to Changing the Behaviour of Residents

After delivery, the occupants should have the capacity to use the technical and digital devices to track their consumption and manage the equipment independently. The Energiesprong specifications stress that this personal monitoring should be "simple to use and accessible to everyone" (Energiesprong, 2021, p. 6). They also specify that the residents should be assisted so that they can use their new equipment to an optimum level.

When they move fully back into their homes (Figure 5), the tenants are invited to a further meeting where the aim is to explain the operation and use of the new systems. Long-term support may be arranged by the building owner or by the maintenance contractor in the consortium, with the aim of explaining to the occupants the right behaviour to adopt in the renovated house. Energy ambassadors can also be established, as happens in the Netherlands: These are people who have already experienced an NZE renovation and want to share their experience and help other households in the neighbourhood to get to grips with the new technologies. However, this approach remains fairly rare in the post-delivery follow-up of residents.

Despite this support, tensions emerge a few months after the delivery, concentrated around two topics: the extent to which the behaviour adopted by residents is consistent with the recommendations set out in the specifications; and the degree to which the occupants appropriate the renovated spaces, in particular the technical equipment and systems. The operation of these systems needs to be understood and practised. For example, the dwellings are very well insulated and use mechanical ventilation, which means that windows should be opened as little as possible. The support and information provided by the landlords resemble coaching. The aim is to push the tenants into changing their behaviour, which they may not enjoy, particularly because of the fact (as we saw previously) that the subject is not introduced sufficiently early on. "That's something, especially in the beginning, that took quite some anger with people because they said: It's quite another way of getting used to it," explains one landlord. An analysis of the language employed by landlords or energy maintenance firms shows that they often use expressions that indicate a normative attitude: "People have to find another way for their drier" (Landlord 1), or "in a hyper-insulated house dwelling with dual-flow ventilation, he [the tenant] needs to understand that he can't behave in the same way as he did with his old house" (Member of energy maintenance firm 1), or else "they [the tenants] have to take care that they're not using too much water" (Landlord 1). It is therefore up to the tenants to adapt and to adopt the right behaviour in accordance with the specifications and following the indications and information provided by the building owner and the consortium. Among these indications, there is also the idea that the new technical system is self-managing and that the ventilation, heating, etc., are regulated automatically. So, the tenants should intervene as little as possible in order not to disrupt the system, which they are expected to trust: "Before, they

Figure 5. Wattrelos. Once the renovation is complete, residents can reappropriate their homes.

[the tenants] had radiators in the living room. When it's cold, you turn up the radiator a little more. Now, they have to trust the system" (Landlord 2).

However, feedback from the building owners shows that these adaptations remain partial. First, the tenants find it hard or are unwilling to abandon their old habits (for example, they continue to open the windows rather than adapting to mechanical ventilation). Second, they may not understand the operation or the purpose of these objects and systems, as one Dutch landlord explains: "People don't know how to use it [the heat pump]. We explained it many, many times, provided people with a lot of explanation about usage, but still, people are not used to it" (Landlord 3; Figure 6). Or else they use the systems incorrectly, for example ignoring a malfunction warning signal which they do not know how to interpret or pressing buttons thinking that they are switching a device on, when in fact they are switching it off, etc.: "People just don't understand the whole concept of all these things being connected" (Landlord 3). What is lost is the very essence of this type of renovation project, the fact that everything is interconnected and that a mistake or wrong behaviour can compromise the energy balance of the whole system. Getting to grips with the new technologies is even more problematic for older people or people who do not speak the language of the country.

Feedback also shows that a partial understanding and a distorted interpretation of the project objectives can actually prompt tenants to adapt their behaviour but in the opposite direction to what the building owner wants. Households remember the slogan "E = 0" but do not link it with the notion of "good behaviour," so they adopt very energy-intensive habits in the belief that their energy bills will still be zero. We heard an example of this rebound effect from the representative of an architect firm in the Netherlands: "You can shower in 4–5 minutes. But if you think: 'I'm living in a very energy-efficient house, oh, I can also shower 10 minutes, it's fine.' Also in other projects, we see this kind of problems" (Architect 1).

While the aim of the Energiesprong approach is to reduce energy consumption and improve housing quality, the scale of the renovation work is so large and the changes so profound that they do not immediately get strong support from tenants. After several sessions to explain the benefits of this kind of renovation, the operation of the technical systems, and the consumption recommendations of the EPC, the project becomes a reality but not everything seems to be resolved. A gap remains: the issue of behavioural habits that are unsuited to a high energy performance building.

3.2. Whose Fault Is It? Mechanisms of Responsibility Sharing in the Event of Overconsumption

As we have seen, for the renovation project to achieve the results that the system is expected to produce and that the building owner and the consortium wants, the ways in which residents use the building and its amenities need to change significantly. In this section, we will raise the question of what happens if this behavioural adjustment does not take place. Who bears the risk associated with the EPC and who bears the cost of any overconsumption caused by misuse of the building? We will see that it is down to tenants to pay for any energy consumption that exceeds level "E = 0," but that arrangements are proposed to manage tricky or potentially conflictual situations.

Figure 6. Heat pumps and meters in Wattrelos.

3.2.1. Overconsumption Caused by Occupant Behaviour

Immediately after the delivery of the renovated buildings, monitoring of their energy performances begins. The tenants receive a letter with the login details needed to track their energy consumption figures online. Monitoring of the performance targets set in the preparation phase of the project is based on the measurement of several indicators:

- The building's total energy consumption (with a breakdown for heating and specific energy use);
- Domestic hot water consumption;
- Renewable energy production;
- Living space temperature;
- Recommended temperature of the heating thermostat.

When the building owner and the tenants obtain the first consumption data, one of two possibilities may arise. In the first, there is a sharp reduction in the energy bill, to the point that it comes close to, reaches, or even exceeds energy neutrality. In this case, tenants will obviously be very satisfied since the financial saving may be significant. In fact, the issue of reductions in energy consumption, although seen in terms of saving money rather than saving energy, becomes central and, as a result, attracts unconditional commitment to the project even from households that had expressed doubts or dissatisfaction in the previous stages, as was explained to us by an expert (who previously worked for a landlord) responsible for supporting landlords in their projects.

The second possibility is that energy consumption remains high. Our study was not intended to measure actual consumption after delivery, and it was not possible to collect quantitative data on this subject through the actors interviewed and for our case studies. Nevertheless, the interviews made it possible to qualitatively highlight the existence of significant performance gaps. A quantitative assessment of these gaps concerning other NZE renovations within the framework of Energiesprong shows differences both in real energy costs compared to the project plan and in households' energy bills compared between them (up to 950 euros per year per household; Borsboom et al., 2015).

This may be caused by the behaviour of the tenants (adopting the "wrong" behaviour or failure to adopt the "right" behaviour, rebound effects, omissions, and mistakes in the managing the technical systems, etc.). A landlord in the Netherlands gives a very striking example:

> I think last week, we even had a lady that said like, 'Oh, I have a really huge electricity bill.' No, it's the whole year she did not use the solar system at all because she switched it off….We have this really, really a lot. (Landlord 3)

In the event of differences between actual consumption and stated performance targets, the measured indicators will be used to assess whether the underperformance is explained by a gap between the actual conditions of occupation of the dwelling and the "normal occupation conditions" defined in the design phase (Energiesprong, 2021). Tracking this will make it possible to assess whether or not the failure to meet the targets—and hence the overconsumption—is attributable to tenant behaviour. If it is not, it is up to the contractor—which provides the EPC in the project consortium—to do what needs to be done to identify the cause or causes of the excess consumption (faults, adjustment, or installation errors, etc.) and to fix them, otherwise he becomes liable to the penalties set out in the contract. If, on the other hand, the excess consumption is attributable to the behaviour of the occupants, it is they who are required to pay the corresponding cost to the energy supplier.

This situation may be problematic for tenants. They will find themselves having to pay for excess consumption, which may equally be the result of free choice (they decide to set the thermostat to 22° C and not 21° C) or of a misunderstanding of how the technical systems work, a wrong setting, etc. The result will be dissatisfaction, complaints, and conflicts between the tenants and the landlord: "Now they [the residents] are using the house and they miss the old kind of heating….There are a lot of complaints, but complaints we can't fix because that's the system we chose" (Landlord 2). In a field case in the Netherlands, the tenants complain to the municipality and ask for help even if it's not directly their responsibility: "That is the problem. People come back and they say, 'You promised me a zero bill, but now I have to pay extra' " (Municipality 1).

3.2.2. Comparison Between Two Economic Models

In the Netherlands, the economic model adopted and enshrined in the Energy Prestatie Vergoeding (EPV) Law in 2016 provides for tenants to pay a sum equivalent to what they spent before on rent and energy, although the latter sum is supposed to be zero after renovation. The whole of this sum is paid to the landlord (while the energy supplier only receives the subscription fee), who therefore receives—in addition to the rent—the sum of money (called the "energy plan") previously paid to the energy supplier and can use the additional money to finance future NZE renovations (Figure 7). This means that, if energy neutrality is not achieved, the household will ultimately have to pay more than before the renovation. The danger of this model is that it could make households even more vulnerable by potentially exposing them to a greater risk of energy poverty.

For their part, landlords are also subject to heavy pressure in relation to tenants, but also in relation to the EPV mechanism, as was explained by a researcher who had worked on this issue: "The house might use too much energy and then they [the landlords] run into

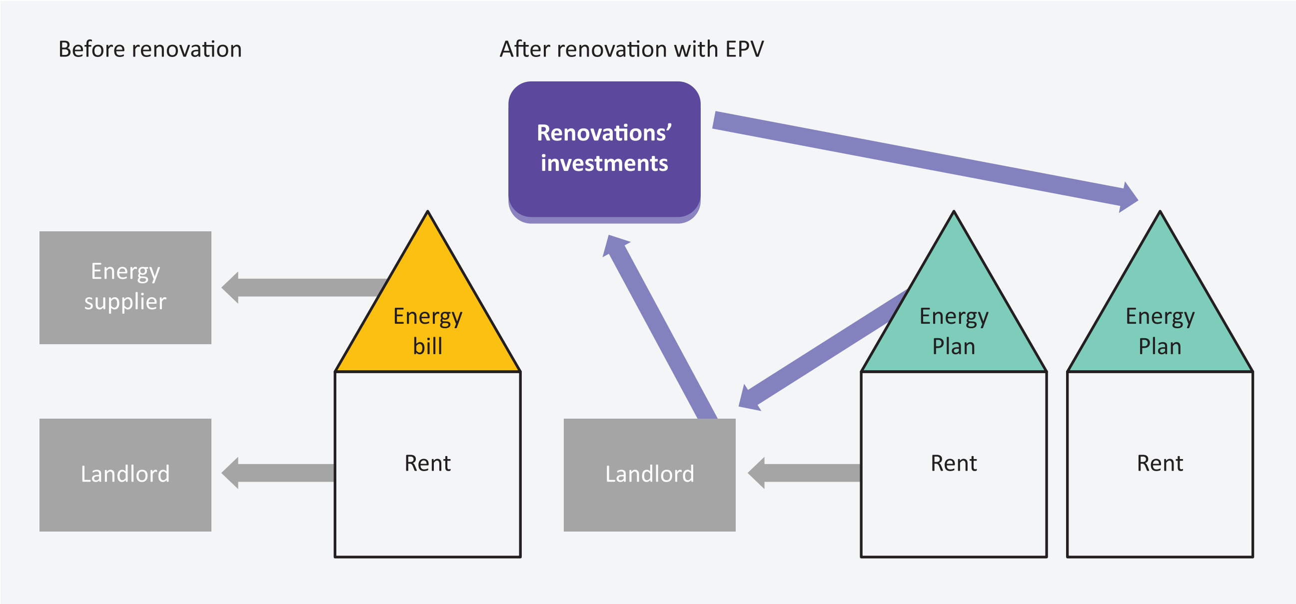

Figure 7. Economic model with EPV.

problems because it combines with the EPV. And it's a housing corporation so the people have low incomes and it's creating a problem of course" (Researcher 1). Indeed, if energy neutrality is not achieved, landlords lose their right to receive the money in the energy plan which is paid directly to them by tenants, unless they are able to show that the building had generated the agreed quantity of energy and that any shortfalls are attributable to the behaviour of the occupants.

In France, the economic model is different because landlords cannot manage the energy for their buildings and rent levels are heavily controlled. Tenants continue to pay their bills, usually significantly reduced, to the energy supplier. Landlords benefit by selling the energy produced by the photovoltaic panels and reinjected into the grid, can make modest rent increases in line with the legal parameters, and, in particular, can increase the maintenance charge through the tenant's energy efficiency contribution: They have the right to do this because they have carried out major energy efficiency improvements. However, by contrast with the Netherlands, the model here assumes that households spend less after renovation than before and that the reduction in the energy bill is much greater than the increase in the service charge and rent, as a French social landlord explained. In France, if there is any excess in consumption attributable to tenants' behaviour, energy bills should still remain lower than they were before the renovation work.

Whereas in France the process is still too recent for data on consumption and energy bills to be available yet, in the Netherlands, building owners have, on the one hand, had to negotiate more advantageous conditions for tenants and, on the other hand, to give a central place to the question of energy uses within the project. For example, one landlord offered the tenants of one of the sites where renovation work was underway the option of a guarantee that their expenditure on energy would never be greater than it was before the renovation:

> The next thing we did is we asked the people to give us their energy bill from the last three years....We made an agreement with them that if the house, the installation doesn't deliver the amount of energy we promised you, then the difference is from that moment on, you'll never pay more than your old energy bill. Everything else above that will be on us. (Landlord 1)

Building owners, but also the project consortia, are gradually realising the scale of the behavioural changes required of the occupants. In particular, they are becoming aware that they underestimated this factor, which has proved to be extremely important to the success of the project, as a landlord in the Netherlands acknowledges: "That also was something we didn't think over before: the complete change of environment for our people who rent our houses" (Landlord 2). This realisation has prompted some actors to question the way in which the specifications are constructed. The standardisation of behaviour assumed in them, as well as the average values calculated, cannot reflect the variety of the social situations within the renovated housing stock or the disparity of behaviours within a single building. A Dutch landlord gives an example:

> The boiler, that was a problem because we designed that thing in a household of 2.85 people. I never saw a household of that size, but we shall work with a family with three, four kids and they all want to shower before they went to work or school. When the mother

> wanted to do the dishes, she had no warm water because the installation was designed at the average of 2.85 people. (Landlord 1)

The need to take the sociodemographic characteristics of the tenants into account has acquired new importance in the eyes of building owners, but also for the intermediate contractors initially charged with developing the approach in the Netherlands (Platform 31):

> A few years ago, we started with the building type, so we made building topologies, but that turns out to be only a very small part of the puzzle because very different people with different social and economic opportunities can live in the same type of building. Of course, that's much more important, or at least equally important to the state of the building. (Platform 31, interview)

In the case of other actors, this realisation has not led to a rethink about the principles of the project, but reinforces the idea of a normative approach that requires a change in behaviour on the part of the tenants and more vigorous oversight of that behaviour, as evidenced by this extract from an interview with a sustainable development official in a municipal housing department: "We can tell people: 'Look, we promised you net zero but that is a technical thing. In real life, it can be higher. So, you have to adjust your lifestyle'" (Municipality 1). The support as currently provided thus seems insufficient, and some landlords recommend that it should be reinforced through the acquisition of new in-house project monitoring competencies.

4. Discussion and Conclusion

The results of our research show that the Energiesprong approach, like other projects of NZE renovation, opted for complexifying technical systems and equipment in order to attain the demanding ambitions of energy neutrality. This choice was made in a context of strong pressure to decrease the consumption volume of the existing building stock, requiring from social landlords a quantitatively and qualitatively high yearly renovation rate.

At the same time, this choice seems to neglect the results of a by now fairly rich scientific and grey literature showing that, for their part, occupants experience difficulties in adopting and adapting to such complex and integrated systems, which may compromise the whole enterprise and generate performance gaps (Gianfrate et al., 2017; Gupta & Gregg, 2016). As our research shows, in accordance with the literature, these performance gaps are characteristic of a number of projects involving the use of new technologies that deeply transform space and call for corresponding behavioural changes. Occupants may not want to change their behaviour, for example, because they prioritize comfort over the reduction of the energy bill (Pellegrino, 2013; Shove, 2003) or because they may simply not understand or be aware of how they should act (as shown also by Gram-Hanssen & Georg, 2018; McElroy & Rosenow, 2019; Topouzi et al., 2019; Zou et al., 2018). In other words, the way in which social landlords and building actors regard occupants' behaviours appears to be very prescriptive and based on the idea that occupants will eventually behave as expected by the EPC. But, as things turn out, occupants are far from behaving as *homo economicus* and do not act rationally and knowingly, maximizing their (selfish) utility and anticipating problems and solutions. As a result, as Geels et al. (2018, p. 24) suggest, "the dominant perspectives on reducing energy demand have a number of limitations and these limitations are reflected in the partial focus and frequent ineffectiveness of the current policy mix."

In this regard, the results of our research concur with and reinforce those of other studies, in particular on the factors that limit and foster the acceptance by residents of innovative renovation concepts (Gram-Hanssen, 2014; van Oorschot et al., 2016); on the need to include residents and give them support before and, in particular, after the renovation, in order to foster acceptance and trust (Sanders, 2020; van der Schoor, 2020); on the opinion of residents regarding the mechanisms of an NZE renovation and the subsequent level of satisfaction with it (van der Schoor, 2020); on the objections to renovations on the part of residents encountered by landlords (van Goor & Brink, 2020); and finally on the importance of taking behaviour into account in projects with an EPC (Jain et al., 2017; Lu et al., 2017).

In addition, this article explores the extent to which residents' behaviours are taken into account in an NZE renovation. It shows how, in all phases of the project, there is a mismatch between the way the project is perceived by the building owner and by the residents (as found by Wekker, 2020). In the pre-project phase, building owners are more interested in achieving a consensus in order to obtain the necessary agreement from tenants for the renovation work to go ahead. The emphasis is placed on improvements in comfort and aesthetic appearance, while the notion of energy neutrality is held in the background. There is very little or no prominence given to the need for residents to adjust their behaviour to the requirements of the new technical systems, and indeed building owners themselves underestimate the importance of this adjustment. Once the building is delivered, the behaviour of residents suddenly becomes a vital issue, because their failure to comply with the project specifications results in excess consumption and hence a failure of the NZE principle. Under the provisions of the EPV law, this failure has serious consequences for both residents and landlords.

What emerges from this research is also that strong performance and guarantee constraints have failed, at least in this approach, to radically change the way in which resident behaviour is considered and incorporated into the project, with the result that the disparities between expected and actual consumption persist. This raises questions about the role of the EPC. On the one hand, it increasingly seems essential to the real success of an ambitious energy project, because it can be used to monitor the project at every stage and to identify the party or parties responsible (and therefore liable to penalties) for any failures and shortfalls from the targets. On the other hand, by setting a framework of essential targets, the guarantee excludes other objectives which, if not met, do not expose the building owner, the contractor, the design office, etc., to possible penalties. In other words, establishing explicit specifications for a set of behaviours that must be maintained in order to guarantee final consumption level signifies, at the same time, that any behaviour by residents that strays outside this framework is not covered by the contract and will make them liable for any impact on consumption.

This opens questions about the overall efficiency of the measure—the fact that an EPC of energy neutrality exists does not imply that actual consumption will be truly neutral, which was nevertheless the primary aim in view—as well as on the responsibility of the actors involved in the process: Who is bearing the risk of this contract?

Ultimately and paradoxically, the self-same technical solutions intended to ensure the success of the approach seem to contribute to its possible failure. This may lead to frustration, which affects building owners as well since, despite the EPC, as a result of the specific project choices, they find themselves facing excess consumption, additional costs, and complaints from residents. Our research findings also show that this frustration and these difficulties are real, but that, so far, they have only led to partial questioning of the fundamental principles of the approach. Some landlords wonder whether the imperatives of reducing energy consumption need to be pushed so far; others, as we have seen, wonder whether the specifications should be changed. More radically, some Dutch landlords are considering the advantages that might come from a more intrusive approach, which is to rehouse the former occupants and bring in new residents once the renovations are complete, who would find it easier to adopt the appropriate behaviour. This approach has already been tried in the Netherlands in operations where the decision is made to demolish and rebuild rather than to renovate and is often accompanied by a change of population.

In the end, there is still a long way to go before the occupant behaviour in a high energy performance renovation project is fully taken into account.

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Conflict of Interests

The authors declare no conflict of interests.

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Article

Residents' Perceptions of a Smart Technology Retrofit Towards Nearly Zero-Energy Performance

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Abstract
Coping with global climate challenges requires changes in both individual practices and the technical infrastructure in which people operate. Retrofitting existing buildings with smart and sustainable technologies shows the potential in reducing the environmental impacts of the housing sector and improving the quality of life for residents. However, the efficiency of these means depends on their individual and societal acceptance. This calls for the need to incorporate social practice theories into the discussion of smart cities and technology adoption. This study aims to understand how smart retrofit intervention in an extensive pioneering smart city project in Estonia is perceived among the residents with different dispositions towards the environment and technology in an early phase of the intervention. We interviewed the residents of 18 Soviet-era apartment buildings which underwent a complete retrofit into nearly zero-energy buildings equipped with smart technologies. The results showed that pro-technology residents expressed high interest and trust towards smart retrofit intervention, while residents with environmentally inclined dispositions conveyed more critical arguments. This indicates that individuals' underlying dispositions may result in different social practices and that a diverse set of engagement approaches are crucial for the success and social acceptance of large-scale pioneering projects in the housing sector.

Keywords
environmental sustainability; nearly zero-energy renovation; smart city; smart retrofit intervention; technology adoption

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

To meet the international climate goals in the housing sector, changes are required both in our lifestyles and in the ways we manage our residential environments. The building and construction sector is responsible for 37% of greenhouse gas emissions globally (United Nations Environmental Programme, 2021). The transition towards nearly zero-energy buildings has been recognised as one of the key pathways to decarbonising building stock and tackling climate change (Esser et al., 2019). The smart city framework, which combines sustainability aims with the means of digitalisation, provides tools and technology for the smart retrofit of existing housing stock (Haarstad & Wathne, 2019; Kramers et al., 2014). Smart retrofit incorporates technological advancements with the efforts of residents to reduce energy demand and improve the quality of housing (Al Dakheel et al., 2020; Hargreaves et al., 2018), which, however, entails several social challenges (Vanolo, 2016). Achieving nearly zero-energy performance with the help of smart technologies requires a systematic socio-technical transition with new forms of collaboration between citizens, governmental institutions, and service providers (Kivimaa et al., 2019). Social practice theories (Reckwitz, 2002; Røpke, 2009; Shove, 2010) provide a framework to conceptualise the behavioural change envisaged by the transition. Social practices necessary for the uptake of smart technologies by residents are formed and transformed in social systems, accompanied by the meaning residents ascribe to the technologies, and supported by the competence to practice smart technology use. Thus, the perceptions people carry and share about smart technologies and smart retrofit may explain the success of the transition.

The possible technologies applied in the smart retrofit range from smart grids to smart home panels (Al Dakheel et al., 2020). Smart technology provides real-time data collection and decision-making options on resource use and system performance on the level of apartments, buildings, and a city (Al Dakheel et al., 2020; Kivimaa et al., 2019). In response to user behaviour, smart technology automates and optimises operations, which helps to reduce carbon emissions and use resources more efficiently (Haarstad & Wathne, 2019; Kramers et al., 2014). However, a rapid uptake of digital technology involves a high risk of citizen exclusion from decision-making, limited use of applied technologies, and poor materialisation of environmental promises (Evans et al., 2019; Haarstad & Wathne, 2019; Hargreaves et al., 2018). A technocratic approach to smart cities and smart retrofit may trigger new types of inequalities in urban life instead of empowering citizens and improving their quality of life (Vanolo, 2016).

Acknowledging peoples' perceptions about the environment and technology and their engagement with technology will help embed sustainability goals within a smart city agenda (Martin et al., 2018). This relies on two assumptions. First, people should be willing and able to practise environmentally conscious lifestyles because technological fixes are not sufficient for attaining sustainability goals (Baum & Gross, 2017; Røpke, 2009). Second, people should be willing and able to adopt smart technologies that facilitate an overall reduction in resource use in their everyday routines. On the one hand, the acceptance and adoption of these technologies largely depend on people's subjective perceptions of sustainability and the usefulness, ease of use, and reliability of the technology (Sepasgozar et al., 2019). On the other hand, top-down implementation of smart technologies in everyday environments accompanied by empowering collaboration between respective public bodies, businesses, and citizens may help overcome people's lack of competence with or fears of technological transition (Berntzen & Johannessen, 2016; Viale Pereira et al., 2017).

In this article, we lean on the theories of social practice (Reckwitz, 2002; Røpke, 2009; Shove, 2010) to analyse the perceived meaning of smart and sustainable technologies being implemented in residential environments to facilitate the transition towards nearly zero-energy buildings and the role of social interaction in shaping those perceptions. We tackle the potential uptake of smart and sustainable technologies in the context of a pioneering smart retrofit intervention, which targets 18 outdated khrushchyovkas, i.e., five-floor apartment buildings designed in the Soviet era for mass housing, in Tartu, Estonia. We examine the perceptions of the intervention among the residents of those buildings. Specifically, we investigate the perceptions among people with different dispositions towards the environment and technology, which have been detected based on their previous social practices. Drawing from Axsen et al. (2012), Mahmoodi et al. (2020), and Sepasgozar et al. (2019), we believe that the underlying dispositions to the environment and technology affect the perceptions of the sustainability, usefulness, and ease of use of the technologies implemented in the smart retrofit intervention and thus the success of the intervention at large. We learn from the experience of the early phase of the intervention before smart and sustainable technologies were implemented into the structures of the buildings and the homes of people. Based on social practice theories, previous practices can affect the prevalence to develop new practices related to sustainable technologies. We evaluate this through the meanings assigned to the technologies and observe the role of social interaction in the process of assigning meanings to the technologies. The assigned meanings allow us to foresee the risks related to the uptake of smart technologies within the retrofit intervention. Furthermore, understanding people's perceptions is crucial for the engagement and collaboration activities within this project and for the overall success of large-scale smart city projects more broadly. Specifically, we address the following research questions in this article:

1. How do residents with different dispositions to environment and technology perceive the meaning of smart and sustainable technologies that are being implemented in a smart retrofit intervention?
2. How does social interaction mediate people's perceptions of smart and sustainable technologies?

2. Theoretical Background

Behavioural change towards sustainable human activity, if supported by relevant contextual opportunities, is believed to be a crucial goal for addressing global sustainability challenges (Barr et al., 2011; Baum & Gross, 2017). As individual consumption decisions are always made in the context of existing consumption spaces and settings, conceptualising behavioural changes needs to occur at the level of social systems (Labanca & Bertoldi, 2018; Røpke, 2009). Adopting technologies can be one example of such behaviour. The diffusion of smart and sustainable technologies implemented in nearly zero-energy housing largely depends on whether and how people adopt the technology in the context of different technological, individual, and social considerations. While the theory of the technology acceptance model (Davis, 1989) describes how technology is accepted on an individual level, social practice theories focus on human behaviour and its evolution in the context of social systems (Reckwitz, 2002).

The technology acceptance model states that people intend to use technology according to its perceived usefulness and perceived ease of use (Davis, 1989; Venkatesh et al., 2003). While possible savings in cost, time, or energy might be important considerations for the uptake (Sepasgozar et al., 2019), several barriers also exist. The barriers can be related to the technology, such as the feeling that the technology has low rates of perceived usefulness, is too complex for use, and has a small relative advantage over its predecessors; or to the individuals as they may lack experience and skills to use the technology, question its reliability, security, and impacts on their privacy, and be resistant to change in general (Balta-Ozkan et al., 2013; Hargreaves et al., 2018; Hong et al., 2020; Marikyan et al., 2019; Sepasgozar et al., 2019).

In addition to individual considerations, people evaluate the benefit of technology in a social context. The acceptance of technology occurs over time through iterative and reflexive social processes, which shape the widespread perception of the meaning of technology (Axsen & Kurani, 2014). Members of innovator and early adopter groups use communication networks to disseminate information to consumer groups that later adopt the technologies (Axsen & Kurani, 2014; Axsen et al., 2013). Individuals may conform due to social norms, social practices, and the behaviour of other people (Axsen et al., 2012; Venkatesh et al., 2003). The influence of social context is also evident in how people perceive themselves when using technology and in how such perceptions are formed concerning other people. For example, individuals may be motivated to adopt new technology for the perceived outcomes to their (self-)identity and social status rather than for the (perceived) functional or (perceived) environmental outcomes of the technology (Axsen & Kurani, 2014; Noppers et al., 2015).

As such, the adoption and consumption of technology are social practices related to a group of people rather than to an individual alone (Nilsson et al., 2018). Social practice theories provide a framework for understanding the evolution and reproduction of human behaviour and its implications for sustainability. This framework understands behaviour as a dynamic and complex interaction between social, material, and individual settings (Hargreaves, 2011; Røpke, 2009; Shove, 2010; Warde, 2005). A social practice is a routinised type of behaviour, which consists of an integrated set of bodily-mental activities that have meanings, are materialised by necessary artefacts, and are practised through the embodied competence of the practitioner (Reckwitz, 2002; Røpke, 2009). Meanings help to define the purpose of the practice and reflect beliefs, understandings, and emotions related to it (Røpke, 2009). Therefore, to understand technology use, one must also understand the meaning that people assign to technology-related practices (see also Warde, 2005). The material element of a practice includes the material artefacts and human bodies involved in the practice (Røpke, 2009). Material objects may involve technologies, infrastructure, or building configurations that are significant for the practice and its development (Bartiaux et al., 2014; Gram-Hanssen, 2010). In cases where a building-related intervention is not directly visible, the acceptance of and adaptation to the intervention is dependent on its visibility through communication and dialogue (Chiu et al., 2013, as cited in Lowe et al., 2018, p. 478). Competence comprises the skills and embodied knowledge of the practitioner (Røpke, 2009) as well as the knowledge contained in repositories, such as manuals or the internet (Watson & Shove, 2008). Competence is obtained through experiences and training and is shared socially (Røpke, 2009; Warde, 2005). Because any social practice is a configuration of these three elements—meanings, material objects, and competence (Røpke, 2009)—the elements also relate to the consequences of the practice. Thus, the environmental outcomes of social practices depend on the meanings people ascribe to the practice, material settings in which the practice is embedded, and competencies embodied in the practitioner or present in social settings. Furthermore, social systems (re)produce and transform social practices, including pro-environmental behaviour and technology adoption, through communication networks, media, and social norms (Hargreaves, 2011; Røpke, 2009; Shove, 2010). Therefore, recognising the impact of social interaction is crucial for understanding the evolution and reproduction of social practices in social systems.

In the context of smart retrofit intervention, understanding these three elements—meanings, material objects, and competence—of intended behaviour and their formation through social interaction gives insights into the process of technology adoption among residents, the environmental outcomes of the behaviour, and the overall success of the intervention. People are willing to adopt smart technologies in their daily life if they perceive them as useful and straightforward (Larsen et al., 2019) and feel control over their features due to possessing necessary skills (Hargreaves et al., 2018). People's involvement in technology adoption may also depend on whether they perceive the technology as pro-environmental. Research has suggested that people representing different dispositions towards technology and the environment may consider different actions as pro-environmental, despite sharing the general intention to contribute to sustainability goals (Axsen et al., 2012). Mahmoodi et al. (2020) suggest that pro-environmental consumer decisions may have radically different meanings for different types of consumers. For instance, a person might conserve household energy for environmental or for financial reasons. Also, involvement influences the environmental outcomes of the intervention and a lack of engagement with sustainable technologies may result in a reverse effect. For example, Strengers and Nicholls (2017) argue that the use of smart-home systems to automate energy use may not meet the goals of energy reduction because the systems are marketed with the promise of convenience (“set-and-forget”) that exaggerates the laziness of users rather than encourages their active engagement in energy-saving practices. Finally, active citizen engagement through communication and dialogue is recognised as “a crucial factor in mediating occupants’ acceptance of, adaptation to, and satisfaction with retrofit technology” (Chiu et al., 2013, as cited in Lowe et al., 2018, p. 478). According to Sørensen (2006), people construct their technology-related practices in interaction with other people’s practices. Thus, social learning can help diffuse competence and innovations at large (Bandura, 1977).

3. Methodology

3.1. Smart Retrofit Intervention in the Pilot Area

Khrushchyovkas are a key part of the Soviet-era housing heritage and are made of prefabricated large blocks or bricks with up to five stories. Built from the late 1950s to the 1980s as an inner-city infill to accommodate people in the post-war housing deficiency (Hess & Tammaru, 2019), they contain small, up to 40 m^2 apartments with one or two bedrooms (see Figure 1). Most of the housing stock in Estonia is privately owned. Residential buildings are managed by apartment associations, which consist of individual owners with equal rights for a majority vote. At present, khrushchyovkas have typically poor sanitary conditions, insulation, ventilation, and heating systems, resulting in an extensive need for renovation (Ahas et al., 2019). The extent of renovation depends largely on the investment capability of residents and available bank loan guarantees (Hess & Tammaru, 2019).

We conducted our research in Tartu, which is the second-largest city in Estonia. The research is centred on a pioneering, smart retrofit project “SmartEnCity—Towards Smart Zero CO_2 Cities across Europe,” funded by the European Union programme Horizon 2020. The project aimed to retrofit 18 outdated Soviet-era apartment buildings (khrushchyovkas) to nearly zero-energy smart buildings equipped with smart home technology. The project carries a “lighthouse project” designation because it is the first large-scale retrofit project in which smart and sustainable technologies were applied to privately owned Soviet-era apartment buildings. In addition to European Union funding, the housing association had to apply for a reconstruction grant from the KredEx financing institution and take a bank loan with a repayment period of 15 to 20 years (Ahas et al., 2019).

The project involved building-level interventions, such as adding insulation, implementing a heat recovery ventilation system, and installing solar panels; as well as apartment- and room-level interventions, such as installing CO_2-sensors and smart home panels that provide automated, on-demand heating and ventilation controls (see Figure 2). The smart home panels allow residents to monitor and adjust room temperatures and airflow intensity using pre-defined settings; monitor electricity and water consumption, and solar energy production; and compare monthly resource use rates with those of the apartment block.

3.2. Data Collection, Classification of Respondents, and Data Analysis

During 2017–2019, we conducted 18 semi-structured and six in-depth interviews with residents who lived in khrushchyovkas within the project area. Our goal was to understand their perceptions of the smart retrofit intervention at an early phase of the project. The socio-demographic characteristics of respondents are presented in Table 1. There are more women than men as well as more respondents with higher education in the sample. However, in terms of age and income, the sample is heterogeneous.

We conducted semi-structured interviews after the apartment associations had been invited to the project, but before they decided to participate. This timing enabled the identification of residents’ perceptions about the retrofit before they had a real-life experience of the outcome. The interviews lasted an average of 45 minutes, were audio-recorded, and later transcribed. The interviews covered residents’ current

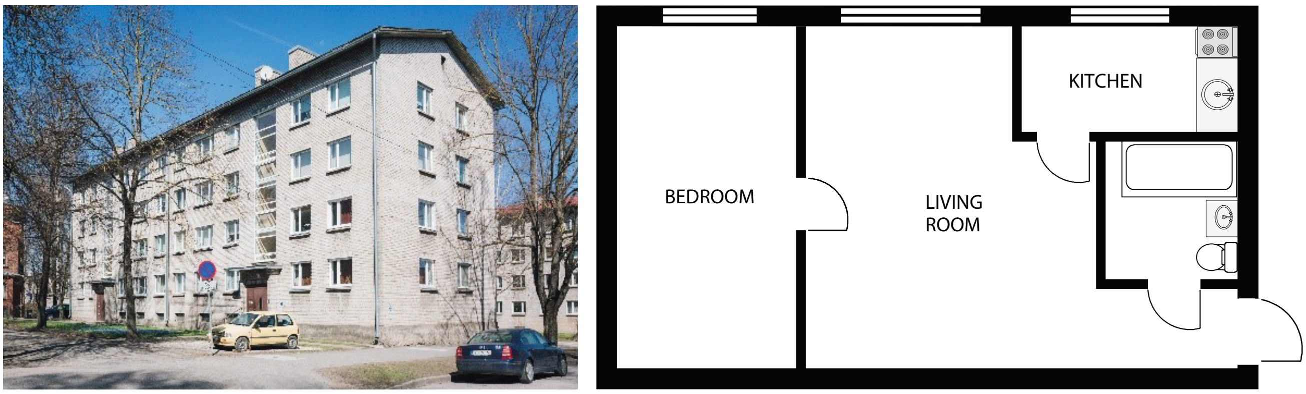

Figure 1. A khrushchyovka-type apartment building in Tartu (left) and a floor plan of a typical apartment in a khrushchyovka (right). Source: Photo courtesy of Silver Siilak.

Figure 2. Smart home panel installed in the khrushchyovka-type apartments, 2021. Source: Courtesy of SmartEnCity project team.

pro-environmental and technology-related practices, attitudes towards environmentally sustainable consumption practices, willingness to use new technologies, and perceptions about the SmartEnCity project. Semi-structured interviews allowed us to identify the thematic categories of meanings assigned to technologies. The semi-structured interviews involved both multiple-choice questions (28 questions) and open-ended questions (29 questions). The questions about pro-environmental and technology-related practices enabled the differentiation of respondents according to their dispositions to the environment and technology. Pro-environmental disposition was identified from questions about consumer practices, such as buying organic products, as well as domestic practices, such as switching off the lights when leaving a room. Questions informing about technology-related disposition targeted the use of electronic household appliances and other electronic devices and interviewees' engagement with digital apps. The respondents used a five-point scale

Table 1. Socio-demographic data of respondents.

Group	Interview Code	Semi-Structured Interview	In-Depth Interview	Gender	Age*	Education	Monthly Income Per Household Member (€)
Bio-greens	2	+		F	55	Higher	321–640
	6	+		F	82	Secondary	**
	7	+		M	28	Higher	**
	9	+		F	80	Secondary	641–959
	10	+		F	63	Higher	641–959
	11	+		M	39	Higher	≥1,601
	13	+		F	30	Higher	≤320
	14	+		M	32	Secondary	321–640
	15	+	+	M	36	Secondary	641–959
	17	+	+	F	54	Higher	≥1,601
Techno-greens	4	+		F	26	Higher	960–1,280
	5	+		F	34	Higher	321–640
	8	+		F	47	Higher	641–959
	16	+	+	F	46	Higher	≥1,601
	18	+	+	F	58	Higher	1,281–1,600
Technocrats	1	+	+	F	51	Higher	641–959
	3	+		M	32	Higher	641–959
	12	+	+	M	38	Higher	321–640

Notes: * Age as it was in the first contact with the respondents in 2017; ** refused to answer.

from "never" to "every day" to report the frequency of individual practices. We aligned the respondents along environmental and technological axes based on their reported average frequency of respective practices. This resulted in the grouping of respondents across the four quadrants of a two-dimensional graph (see Figure 3). We identified pro-environmental technology users as "techno-greens,'' pro-environmental technology non-users as "bio-greens," and environmentally ignorant technology users as "technocrats." None of our respondents was identified as an environmentally ignorant technology non-user.

In the next phase, we approached two respondents from each identified group to conduct in-depth interviews. The six in-depth interviews occurred after respective apartment associations had accepted the invitation to participate in the project. In the interviews, participants were able to freely talk about how they perceived the project and smart technologies without a (direct) influence by the researcher. These interviews were less structured, and the interview guide consisted of open-ended questions about the main topics: (a) the likely outcomes of the project for the respondents, the city, and the environment more broadly; (b) respondents' opinions of the planned retrofit action both on the building and on the apartment level, including the smart home system; and (c) respondents' likely future engagement with the smart home system, including their skills and competence to handle the technology. In addition, the interviews addressed social interaction, which the respondents were engaged in and which mediated their understanding of the project. With the data from the in-depth interviews, we were able to provide explanations to the perceptions that the respondents assigned to the technologies and the intervention more broadly and relate the perceptions to the potential uptake of the technologies in the future. All the quotes were taken from in-depth interviews. The in-depth interviews lasted an average of 60 minutes.

For the data analysis, we applied the summarising type of qualitative content analysis with inductive thematic coding of interview data. We extracted and coded

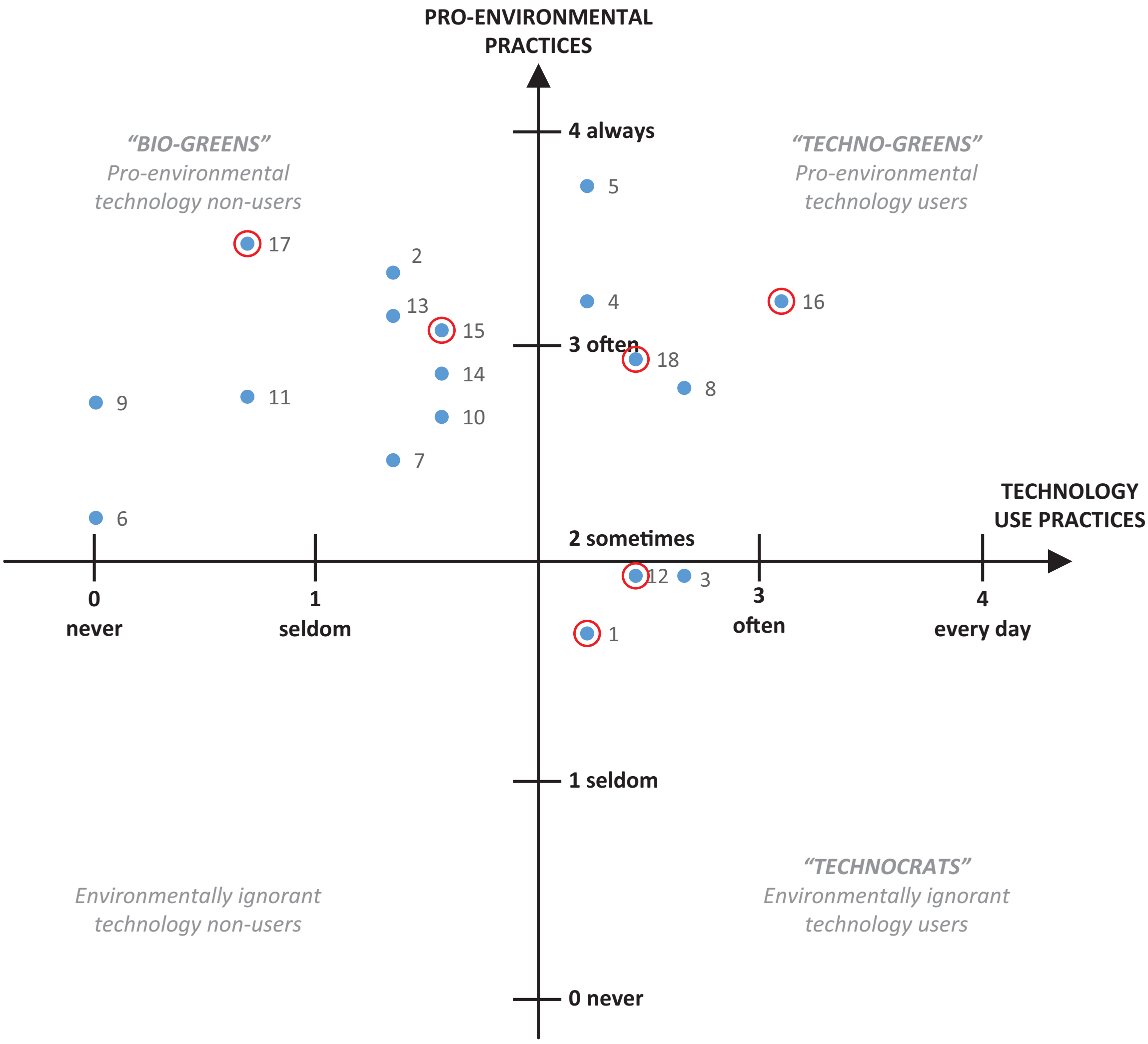

Figure 3. Respondents' positions on the axes of pro-environmental and technology use practices. Blue dots indicate respondents and red circles indicate those who also participated in the in-depth interviews.

excerpts of the interview transcripts to identify respondents' perceptions about the intervention and to analyse the role of social interaction as a mediator for technology acceptance. Because of the timing of the interviews, the respondents had not yet developed new social practices for adopting smart and sustainable technologies. Therefore, we distinguished the meanings people assigned to the forthcoming intervention and analysed them as an indicator of the meanings they might also assign to the social practices required for accepting the technologies.

4. Results

4.1. Meanings Assigned to the Adoption of Technologies Among Respondents With Different Dispositions

We identified six domains of meanings that respondents assigned to the smart retrofit intervention based on the semi-structured interviews (see Figure 4): (1) environmental impacts, (2) health impacts, (3) technological concerns, (4) financial considerations, (5) usefulness and personal comfort, and (6) symbolic and emotional values. We used the in-depth interviews to provide further clarification and reasoning to the meanings, indicated by respondent quotes below.

4.1.1. Environmental Impacts

Residents showed both trust and scepticism towards the potential environmental impacts of the smart retrofit intervention. In general, technocrats tended to emphasise the intended positive effects of the intervention by acknowledging that it would produce sustainable energy and improve the energy efficiency of the buildings. Respondents in both the bio-green and technocrat groups pointed to the benefits for land use: The retrofitted housing would reduce the need to develop new residential areas at the expense of urban greenspace.

In addition to the identification of the positive effects, bio-green and techno-green respondents also expressed environmental concerns about the intervention. They were not always convinced that smart and sustainable technologies, rather than traditional solutions, had environmental benefits. They argued that the production of such technologies requires more resources than would be saved by their use. They also pointed to the low durability and short life cycles of smart technologies, which are driven by market forces, quick obsolescence of IT systems, and consumer preferences, and result in unnecessary pressures on the environment:

> Well, the benefits of technology depend on how the technology is produced and how long it lasts. Excessive innovation is certainly more harmful to the environment than living without technology. (Female participant, 34 years of age, a techno-green)

Respondents from the bio-green and techno-green groups claimed that the total environmental impact of the intervention depends not only on what technologies

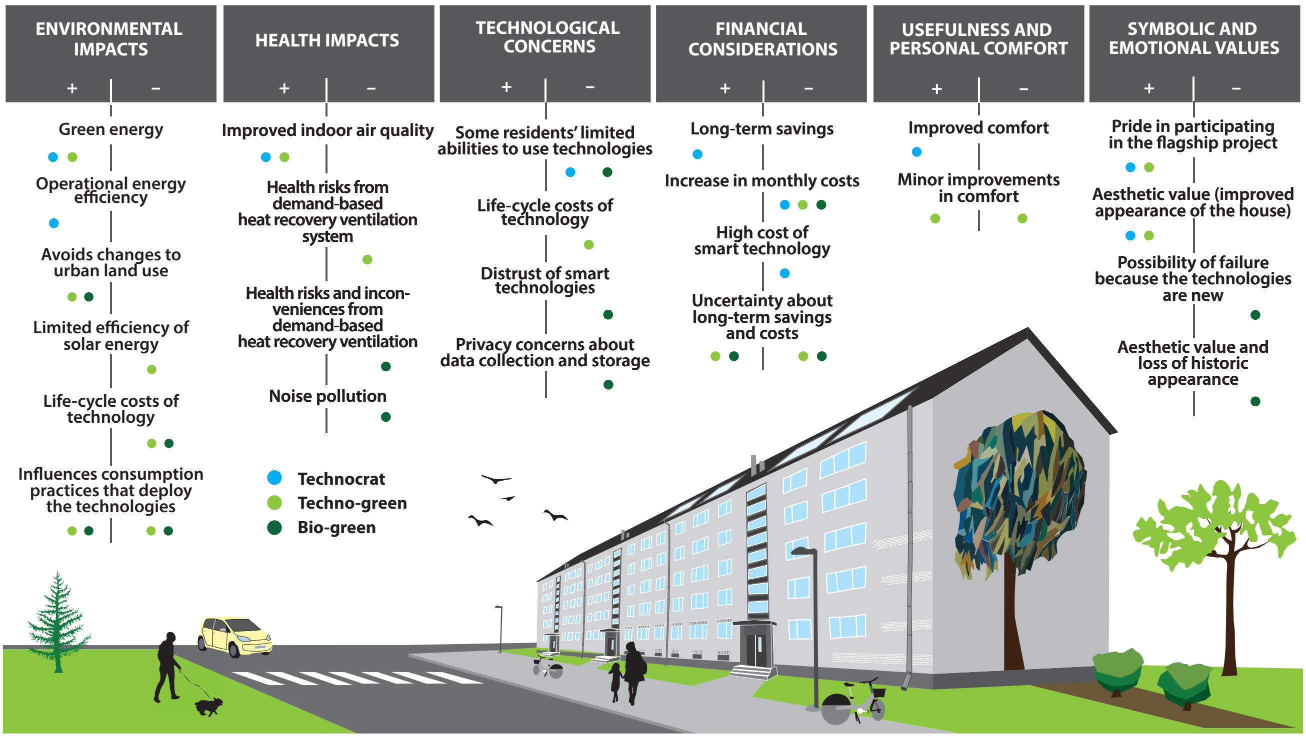

Figure 4. Meanings assigned to the smart retrofit intervention from respondents with different environmental and technological dispositions. The symbol "+" indicates a positive attitude and "–" indicates a negative attitude.

are implemented but also on how residents use the technologies:

> I think that technology has its advantages and disadvantages because it contributes to saving the environment, but it can also harm the environment. However, technology as such cannot be solely blamed for environmental damage; there is always a human aspect involved, such as individual awareness and economy. It is important to find a balance between social and environmental aspects. (Male participant, 28 years of age, a bio-green)

4.1.2. Health Impacts

Views on health impacts due to the changed indoor climate shaped respondents' overall perceptions about smart technology intervention. Technocrats and some techno-greens believed that the intervention would significantly improve indoor air quality because the Soviet-era apartment buildings had poor air circulation:

> This project provides better air quality to the residents because some apartments do not have fresh air, and some are so humid because of poor ventilation. All in all, the retrofit will improve the life quality afterwards. (Female participant, 26 years of age, a techno-green)

Most bio-green and some techno-green respondents questioned the positive health outcomes. They believed they would experience considerable inconvenience in terms of indoor air quality, noise pollution from the automated ventilation system, and consequent unintended health impacts. For example, one bio-green respondent stated their preference for natural ventilation and their belief that the air produced by a demand-based heat recovery ventilation system would not be as fresh as the outside air.

4.1.3. Technological Concerns

Respondents in all groups raised concerns about developing the necessary practices and the required degree of technical experience to deploy and interact with smart technologies. Several respondents perceived the intervention, especially the smart home system, as unnecessary, unreliable, socially exclusive, or a threat to privacy. A few bio-green respondents were worried about the potential abuse of their personal consumer data either by those who stored it or due to illegal access to the smart home system and their data:

> Many people can actually cope with technology, but they just can't accept the change mentally. Alright, they will learn and use it, but then there will be an update that will completely change the situation. And people get a mental block…and develop negative attitudes. It's not all about skills but how you make sense of the technology for yourself. (Female participant, 51 years of age, a technocrat)

One bio-green respondent (female participant, 54 years of age) highlighted the importance of considering specific users' needs and preferences when designing technology to enhance its utility. She pointed out that the design should consider the technological competencies of older people, including their preference for large icons and easy navigation menus, as a user-centric design would improve their willingness to use the technologies.

4.1.4. Financial Considerations

Respondents from all groups were aware that their monthly expenses would increase during the loan repayment period. However, the groups had different understandings about the net costs or benefits of the retrofit, partly because of uncertain future energy prices. In general, the technocrats expressed a belief in net savings in the long run. Bio-green respondents on the other hand tended to believe in no notable changes to their energy bills once the construction had finished. Although they agreed that the new insulation would decrease the heating costs, a few in the bio-green group were concerned about an increase in electricity costs due to the demand-based heat recovery ventilation system. Techno-green respondents expressed mixed attitudes towards changes in monthly expenses with similar arguments as expressed by other respondents.

The technocrat and techno-green respondents believed that the extensive energy-efficiency intervention would result in an increased value of their real estate. However, several bio-green respondents expressed doubts about the potential increase in real-estate prices. Respondents from each group appreciated the European and local funding that enabled the extensive retrofit of the buildings, including its technical systems, facade, windows, doors, and staircases. Without external support, the housing associations could not have afforded to renovate the buildings to nearly zero energy.

4.1.5. Usefulness and Personal Comfort

Those in the technocrat group frequently cited improvements to personal comfort that would come from using sustainable technologies in support of their future use of smart technology. They identified benefits from the smart metering and automated operation system because they would be less involved in adjusting the heating or ventilation settings:

> A smart home panel with monthly consumption feedback will definitely change my life. It is important to me that I can set home systems to operate automatically with less effort. (Female participant, 51 years of age, a technocrat)

While bio-green respondents did not comment on comfort-related benefits, techno-green respondents recognised the reduced need to adjust the heating and ventilation system. However, they did not emphasise comfort as an important factor in preferring smart technologies and instead noted their low practical value:

> Maybe I just don't appreciate all those nice things enough, for example, that bathroom ventilation automatically starts when I take a shower. It's probably good that everything can be adjusted from a distance with a smartphone. But I don't need it. I don't need to be able to regulate heating and see the meters' information from a tablet—it's like a duplicated system. (Female participant, 58 years of age, a techno-green)

4.1.6. Symbolic and Emotional Values

All groups expressed a range of symbolic and emotional values about the intervention in general, which could also affect the mindset towards the applied smart technologies specifically. Most respondents found the renovated buildings to be visually attractive and aesthetically appealing. Some in the technocrat and techno-green groups appreciated the pioneering state of the project to retrofit Soviet-era residential buildings as this would encourage future retrofitting initiatives:

> It's very nice that such khrushchyovkas will be retrofitted and that the project deals with old, not new houses. There are many khrushchyovkas in Estonia and this project could initiate a motivation for other housing associations to retrofit their buildings into nearly zero-energy houses as well. (Female participant, 26 years of age, a techno-green)

However, a bio-green respondent (male participant, 32 years of age) questioned the pioneering aspect of the project and worried that residents were test subjects for technological solutions that had not yet been tried elsewhere. He preferred to opt out of the experiment and to use more tried and tested solutions.

4.2. Social Interaction Shapes the Meanings Assigned During the Intervention

Respondents in all groups stressed the importance of receiving information and user guidelines about the project, its outcomes and impacts, and the technologies to be installed. They referred to four types of social interaction throughout the interviews: (1) contacts with the project team, (2) attending apartment association meetings, (3) relying on informal networks, and (4) researching on the internet.

The official source of the information was the *project team*, through multiple informative and instructive visits to each building during the planning and implementation phases of the project. However, our respondents expressed their concerns about the lack and ambiguity of information about the project throughout its multiple stages, and their wish to be more engaged throughout the process. The poor quality of information created confusion, negative feelings, and distrust, especially in several bio- and techno-green respondents:

> At the moment, someone designs something, somebody builds something, but without discussing it with residents. Some people take this construction process as a frightful bore. I believe that this is because of the lack of communication between residents, construction companies, and the apartment association board. (Female participant, 46 years of age, a techno-green)

The main forum for discussing the intervention was the *apartment association meetings*. Respondents' technology-related dispositions either reinforced trust (among technocrats) or uncertainties (among bio-greens) about the project, resulting in heated discussions. People who had less trust in technology felt that their concerns were not addressed equally during the meetings because technology-oriented members were claimed to close down any discussion of the possible disadvantages of the project.

> We have argued a lot in the meetings. Nobody talks about the disadvantages and threats that accompany the retrofit. I understand that it is proud to be part of the pilot, but many people are not heard. Not everyone confirmed to participate in the project. This decision was made by a majority vote.... These people went for the retrofit in the faith that technology helps. Actually, they have no proof that it does. (Female participant, 54 years of age, a bio-green)

Respondents believed that the development of a meaningful understanding of the technologies involved in the intervention was time-intensive. Due to the uncertainties in project communication, residents had to allocate their time to acquire information through *informal networks* and *the internet*. Bio- and techno-greens frequently discussed the financial, environmental, and health effects of insulation with their friends and acquaintances. The perceptions of their peers shaped their understanding of the technologies. Nevertheless, several bio- and techno-green respondents were concerned that pro-environmental practices would not be developed given the low level of social cohesion and community support that they claimed to prevail in khrushchyovka-type housing.

5. Discussion and Conclusions

The meaning of the smart retrofit intervention to provide nearly zero-energy housing is heavily affected by people's previous dispositions towards technology and the environment. Dispositions are the "foundations" that indicate how information is processed and trusted and how people perceive technology, making them important prerequisites for developing social practices (Hargreaves, 2011; Røpke, 2009; Shove, 2010). The promises of energy efficiency and implementation of solar energy solutions create affection towards the intervention among respondents with pro-technology dispositions as the solutions are perceived as beneficial to the environment. Yet, pro-environmental dispositions tend to raise concerns about the overall environmental impact of the intervention due to its uncertain life-cycle costs. The identified differences in respondents' perceptions about the environmental impact of the project corroborate the discussion of Axsen et al. (2012) who refer that the term "pro-environmental" varies in meaning among people with different environmental and technological dispositions. Specifically, they consider the variation of meaning in the field of mobility behaviour: While "techies" might buy electric vehicles to reduce their environmental impact, "low-tech greens" might prefer to reduce their overall mobility instead. Such differences, in turn, shape the development of pro-environmental practices: The meaning residents assign to the smart retrofit intervention in general and the deployed technologies in particular influence their individual processes of adjustment to the intervention in their everyday life.

The meaning is also perceived through usefulness, financial considerations, symbolic values, and health impacts. Personal gains from smart technologies, such as comfort, improved indoor climate, and long-term net financial savings attract people with stronger pro-technology dispositions. Comfort-related incentives of smart technologies are frequently identified in the literature as aspects supporting technology adoption (Marikyan et al., 2019). However, previous research has suggested that comfort-related benefits, such as "set-and-forget" type of solutions, may in the long-run decrease people's engagement with energy-saving practices and technology (Strengers & Nicholls, 2017). Increasing personal comfort through automation reduces personal responsibility in energy savings and may thus undermine individuals' role in achieving the sustainability goals of the project (Barr et al., 2005).

Unfamiliarity with technology and social exclusion risks raise concerns about the adoption of a smart home system. Respondents with pro-environmental dispositions were concerned about the adoption of and physical engagement with smart home systems, especially concerning the ease of use, reliability, and privacy of the technology. Specifically, respondents believed that the smart home panel used to control the system was not suitable for older residents. Previous research has highlighted the role of competency in obtaining new social practices: Limited technical skills, lack of interest in, and fears of the technological features act as barriers to technological transition and prevent people from accepting and adopting new technology (Hargreaves et al., 2018; Hong et al., 2020; Marikyan et al., 2019). A co-design approach could help tailor the design and thus avoid possible social exclusion from the start (Hargreaves et al., 2018; Lowe et al., 2018).

Knowledge acquisition and community support are prerequisites for creating new collectively shared practices. Our interviews demonstrate that residents followed different social interaction strategies to develop a meaningful understanding of the retrofit intervention. Social interaction with the project team and peers from the housing association and informal networks helped residents collectively ascribe meanings to the intervention and related technologies. According to Røpke (2009), the development of new social practices is a dynamic process that incorporates gradual changes in the competencies of practitioners and the meanings people attach to practices through social interaction. The results of this and previous research (e.g., Chiu et al., 2013; Lowe et al., 2018) indicate the importance of communication and engagement with the residents throughout the reconstruction process towards nearly zero energy performance. Social learning (Bandura, 1977) can help to diffuse competence as well as innovations in general.

This study contributes to the human-scale approach to smart cities. Critics of the smart city approach emphasise that the framework lacks a true citizen perspective (e.g., Evans et al., 2019; Vanolo, 2016). Our results indicate that people's dispositions towards technology and the environment should receive more attention than scholars of smart and sustainable technology have previously allowed. The connection between dispositions, innovative technological adoption, and pro-environmental behaviour of people is the collective development of social practices that—if targeted wisely—promise to make a human-scale, smart city approach acceptable to people with various backgrounds, understandings, and beliefs. This approach bridges two often non-overlapping goals: "going smart" and "going green" (Gazzola et al., 2019), and, thus, enables planners to embed sustainability goals such as nearly zero-energy performance into a smart city agenda (Evans et al., 2019).

The limitations of the study call for further research. We acknowledge that grouping respondents based on their pro-environmental and technology-related practices is a simplification of people's conceptions of the environment and technology, and how these develop over time. A follow-up study after the project is completed would provide valuable knowledge of the true social acceptance of smart retrofit intervention and its technologies. To reach a complete understanding of the human perspectives of a smart retrofit intervention, an in-depth examination of the perceptions of other stakeholders, such as the project team and representatives of the apartment associations, is needed.

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Conflict of Interests

The authors declare no conflict of interests.

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Article

The Comfort Tool: Assessment and Promotion of Energy Efficiency and Universal Design in Home Renovations

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Abstract
This article introduces a method for advancing environmental and social sustainability objectives in relation to home renovations laid out in European and Belgian policies. The comfort tool is an instrument that simultaneously addresses the energy efficiency and universal design aspects of a sustainable home renovation while being usable and meaningful to laymen homeowners and improving their communication with building professionals. It is based on recent research exploring a synergetic merging of energy efficiency and universal design in housing through the concept of indoor environmental comfort. It employs comfort as a way of intervening in the decision-making process for energy efficiency and universal design measures in home renovations. The comfort tool takes a user-centered approach and rests on an interdisciplinary set of theoretical constructs bringing together knowledge from psychology, nursing, design, and building sciences. Besides describing the method itself, the article lays out the theoretical underpinnings and motivations behind its development and discusses relevant future considerations for sustainable home renovations research and practice.

Keywords
comfort; comfort tool; energy efficiency; home renovation; universal design

Issue
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1. Introduction

In response to societal and policy goals on environmental and social sustainability, this research begins from the idea of merging energy efficiency (EE) and universal design (UD), two fields that are typically considered separately in home renovations. The assumption is that merging them could lead to an increased adoption of both in-home renovations by providing a more appealing package of renovation benefits to homeowners.

However, there is a misalignment of objectives between policy and societal objectives for greater application of EE and UD in home renovations and the individual objectives of homeowners when planning home renovations. Renovators are more concerned with the direct perceived impact of renovation measures on themselves and their families, rather than the effect of measures on society. Non-energy benefits appear to be important motivations for homeowners considering renovation measures, with comfort appearing as a key factor in a wide variety of quantitative and qualitative EE studies (Aune et al., 2011; Bartiaux et al., 2014; Grandclément et al., 2015; Mills & Rosenfeld, 1996; Straub et al., 2014; Velux, 2015) while improving the general sense of comfort for the greatest number of occupants is an underlying goal of UD in housing (Steinfeld & Maisel, 2012).

1.1. Tools and Methods for Promoting Energy Efficiency and Universal Design

A significant number of labels and assessment systems have been researched that address EE and UD in housing, although they do so separately. These tools are often created by and for building professionals such as architects, engineers, and builders, resulting in tools that are relatively objective but uninspiring, opaque, and either too blunt or too detailed and impractical for small projects like home renovations where the key decision-makers, the homeowners, are not able or willing to use professional tools.

Checklist-style methods such as the Zilveren Sleutel (Inter, n.d.) by Inter in Belgium, Lifetime Homes in UK (The Foundation for Lifetime Homes and Neighbourhoods, 2016b), and Liveable Homes in Australia (Livable Housing Australia, 2020), are prescriptive in nature and focused on accessibility and disability, rather than the broader design topics covered by UD. The isUD (self-)certification initiative recently launched in the United States takes a more advisory approach by highlighting innovative solutions for UD as a way of increasing adoption of UD (University at Buffalo Center for Inclusive Design and Environmental Access, 2021). isUD is modeled on the more famous ecological assessment tools, LEED and BREEAM, but with the focus, as the name implies, on UD alone.

On the energy side, in Belgium, the RenovatieStarter (Renofase, n.d.) and MijnBENovatie (Vlaams Energieagentschap, 2017) tools are designed to be simple to use and understand by renovators but, as a result of EE government initiatives, are limited to explaining EE measures for their economic or environmental benefits. The EPB-software energy demand calculation software (Vlaams Energieagentschap, 2021), the obligatory standard in Belgium and similar to the RdSAP in UK, gives a detailed and relatively accurate understanding of the home's energy demand. It is, however, also only focused on EE and far too complex and detailed for most users, including many architects.

Indoor environmental quality (IEQ) is a key concept in EE research. Its four main parameters (light, air quality, noise, and thermal comfort) define the comfort goals against which the EE of a building is measured. Frontczak and Wargocki (2011) reviewed the literature on the importance of IEQ parameters on perceived comfort and developed a "template" questionnaire survey for comfort (Frontczak et al., 2012). Kim and de Dear (2012) show that the relationship is not linear. A wide variety of assessment models have been developed (Heinzerling et al., 2013) which most recently aim for "holistic" assessments of IEQ (Leccese et al., 2021; Rohde et al., 2020). However, despite the name, the holistic IEQ assessment methods are, by their nature, confined to the four main parameters of IEQ—light, air quality, acoustics, and thermal comfort—thus not addressing other (universal) design-related aspects that can contribute to perceived comfort in buildings.

The ambitiously named Perfection research project (Huovila et al., 2010) and the design quality indicator (Gann et al., 2003) have made significant strides towards developing a comprehensive set of building quality key performance indicators that take into account environmental performance as well as other spatial, design, and health concerns. However, both are designed for professional use and get weighed down by the complexity of several dozens of indicators. Particularly in the case of Perfection, the indicators require a multitude of experts to understand and assess appropriately. The design quality indicator stands out from the rest for trying to assess subjective design indicators while acknowledging that the measurements in fact have only meaning in relation to the "intents" of the project. The authors point out its value as a tool for thinking about design and as "a starting point for discussion" that facilitates the writing of the design brief and improves communication during the design process.

The RENO-EVALUE project (P. A. Jensen & Maslesa, 2015), in Denmark, aims to place the energy savings and quality of life in the same equation when calculating the economic value of a project. It is a type of multi-criteria decision-making support tool for sustainable renovation projects which can also be used for assessment after construction. The main purpose is to provide a process tool that can identify each stakeholder's priorities and help establish common criteria for success, weighted subjectively by the stakeholders in the early phases of large-scale renovation projects, like social housing buildings (S. R. Jensen et al., 2017). RENO-EVALUE is intended for use on large-scale projects in the professional sector by housing associations, project managers, designers, etc. It is not suitable for small projects without professional clients, like single-family houses.

There has been some more recent work to provide tools and concepts that could help to more holistically understand and motivate homeowners in their home renovations. Kerr et al. (2018) consider renovators as a heterogeneous group and disaggregate them in four renovation narratives that take into account the general home renovation experience as indistinct from an energy renovation.

Wilson et al. (2015) first suggested a situated approach and then developed a contextually rich model (Wilson et al., 2018) for understanding the motivations and process of how homeowners renovate. The model they develop takes into account background conditions of domestic life which spur renovation and identify three particularly influential ones: balancing competing commitments for how space at home is used, signaling identity through homemaking activities, and managing physical vulnerabilities of household members. These, in effect, represent comfort indicators *Usability of spaces* in the first; *Image & identity* and *Elegance* in the second; *Accessibility*, *Safety*, and *Security* in the last. Their model, tested on a UK sample, shows that renovation intentions begin based on these non-energy factors, but the influences on renovation decisions shift during the process. Thus, the authors recommend that "efficiency measures should be bundled into broader types of home improvements, and incentives should target the underlying reasons why homeowners decide to renovate in the first place" (Wilson et al., 2018, p. 1333). The work of Wilson et al. (2015) demonstrates quantitatively many of the same issues and drivers of our own research, such as the focus on non-energy influences on renovation decisions and the idea of bundling EE measures. In contrast, their model is aimed for use by researchers and policymakers to understand renovators rather than for directly influencing the renovators in the decision-making process.

While this is not an exhaustive list of EE or UD tools, to our knowledge it is representative of the current relevant research. It reveals that, even in the rare cases when a more holistic perspective is taken, the intended target is not the homeowner or their aspirations for their home. Hence, at present, there is no tool that: (a) takes both EE and UD aspects into account, (b) points out parameters for improvement from the point of view of the house owner, (c) is sufficiently easy to be used and understood by laymen, and (d) improves communication between house owners and professionals. This article proposes the comfort tool (CT) method as an answer to this knowledge gap.

1.2. Goals and Positioning of the Comfort Tool

The CT is a novel user-centered method for promoting both EE and UD measures in private home renovations. It is an instrument for eliciting the subjective level of indoor environmental comfort (IEC) from the perspective of the inhabitants. Its direct objectives are trifold.

The main purpose of the CT is to raise awareness of EE and UD measures in relation to their impact on comfort at home. It focuses on the perceived benefits of renovation measures, what the people actually experience, rather than on the measures themselves. In other words, it deals with the (non-energy) benefits of EE and the (non-disability) benefits of UD. It broadens the scope of needs or desires of a renovation, and, by extension, it aims to broaden the scope of associated measures to be considered when thinking of renovating. For example, the need of replacing an old window can open up questions about natural light (the size and dimensions), temperature (double or triple glazing), maintenance (the frame material and direction of opening), or accessibility (location and type of handles).

The target group of the CT is home owner-occupiers who have the rights and incentives to renovate but are generally not designers or experts in home renovations. For this reason, the second objective of the CT is to be very simple to use, easy to understand, and yet meaningful in both input and output. In other words, it should measure and output something that is both understandable and relevant to the average homeowner.

Finally, the CT aims to improve communication between residents and experts or building professionals advising in the decision-making process. Homeowners are usually not building experts and often do not have the right vocabulary to explain what they need or why they need it. The tool strives to be a catalyst for deeper, broader, and easier to articulate conversations that start from needs and desires rather than solutions.

For these reasons, the CT does not attempt to be (yet another) source of prescriptive yet general renovation advice. Instead, it is only intended to serve as a platform that energizes and arms would-be-renovators with the right kind of questions, priming them for a discussion with an expert. This approach recognizes the old mantra that "there is no good architecture without a good client." It also recognizes the immense diversity of home renovation situations, diversity of personal preferences, and the ability of designers and other professionals to provide creative and personalized solutions.

In recent research, comfort is identified as an important driver in pushing people forward between each of the four phases of the decision-making process (Klöckner & Nayum, 2016). The phases start from "not in decision mode," which means that the person is considering the idea of a renovation but is not yet making any decisions. A series of barriers and drivers affect the move to "deciding what to do," then on to "deciding how to do it," and finally to "deciding how to implement." The CT is intended to be used largely in the early phases encouraging a shift from "not in decision mode" to "deciding what to do." Here it can help to incentivize residents to consider EE and lifelong living measures by framing them as aspirational comfort measures and by improving communication with the architects or other relevant advising professionals. This approach is supported by Kerr et al. (2018) who argue for developing "holistic narratives" for renovations as people typically don't distinguish energy renovations from a general home renovation. It should be emphasized that the target group is people who are already thinking about renovating but are not sure what to do yet. It is not meant for people who are not considering any renovation works at all.

The article first describes the theoretical foundations and previous research on which the CT method is built upon. The development process and methods are then outlined, followed by a detailed explanation of the different elements that make up the CT method as derived from the theory. Finally, we discuss the CT's limitations and current and future considerations relevant to the practice and research of EE and UD in home renovations.

2. Three Theoretical Pillars of the Comfort Tool

2.1. Comfort as a Product

The first theoretical pillar for the CT is the view of comfort as a product with an associated set of indicators. Comfort is a complex, socially constructed, evolving, and variously understood and debated concept. When used as an umbrella encompassing EE and UD, it is necessary to differentiate between product and process.

Kapedani et al. (2016) have argued that UD and EE are concepts of a different type, UD being a process and EE a product, and that in order to treat them concurrently we need to compare both at the same level. UD and associated terms such as "inclusive design" and "design for all" are most often understood as a process or paradigm for designing buildings (as well as products and services) that are usable by all people to the greatest extent possible (Iwarsson & Ståhl, 2003; Ostroff, 2011). However, we focus on the output or product outcome of the UD process. This interpretation of UD is arguably more in line with the earlier descriptions by Mace (1998). For clarity, in this article, we use the term "lifelong living" which can be considered as a physical manifestation, product, or design output of a UD process. Similar concepts are called "lifetime homes" in the UK (The Foundation for Lifetime Homes and Neighbourhoods, 2016a), "livable housing" in Australia, etc.

A framework that describes IEC as the aggregate impact of the physical features of a home on the inhabitant's individual sense of perceived comfort (Kapedani, Herssens, & Verbeeck, 2017) is used as the basis for the CT. It takes a socio-technical approach and uses as a starting point Shove's (2003) analysis of comfort as a socially constructed concept (see also Shove et al., 2008), and the historical evolution of the notion of comfort at home outlined by Rybczynski (1986). It goes far beyond the technical definitions of thermal comfort. IEC encompasses aspects discussed in IEQ literature (temperature, light, noise, and air quality) as well as design and spatial aspects associated with lifelong living (such as maintenance, accessibility, and safety; Figure 1). The comfort assessed by the CT is thus a product—a socially constructed and individually perceived product, made up of 16 indicators which are further explained in Section 3.1.

2.2. Comfort as a Relative Concept

Comfort as concept that does not have a meaningful absolute value is the second theoretical pillar. Although there are a myriad of definitions and understandings of the concept of comfort, including in the fields of architecture and EE, the CT adopts a particular understanding of comfort as mainly used in nursing literature. Kolcaba and Kolcaba (1991), Kolcaba (1994), and Kolcaba et al. (2006) have progressively explored its meaning, applicability, and measuring tools in the healthcare context. A key feature of comfort in nursing is its lack of an absolute value. In other words, not only is comfort differently perceived by different people, but it is also differently understood by the same person in a different situation. It acknowledges that a nurse cannot measure the absolute level of comfort felt by the patient but only the improvement of perceived comfort felt by the patient as a result of an intervention by the nurse (such as providing medicine, a blanket, or just holding the patient's hand).

This understanding of comfort implies two things: (a) comfort is relative in the sense that it depends on the person perceiving it, so the same home could result in a different sense of comfort for different people; and (b) when measuring comfort there are three elements: an intervention, perceived comfort before the intervention, and perceived comfort after the intervention. In the context of comfort at home, the intervention is the act of renovation—physically changing the home. Therefore, measuring the relative improvement of a renovated home is in fact a measurement of the ΔComfort—of the change in comfort as a result of a renovation from the point of view of the inhabitant who compares perceived comfort before the renovation to perceived comfort after the renovation.

2.3. A Person–Environment Fit

The third theoretical pillar for the CT is the person–environment fit (P–E Fit) theory. The P–E Fit theory originated in the 1970s, with Lawton and Nahemow (1973).

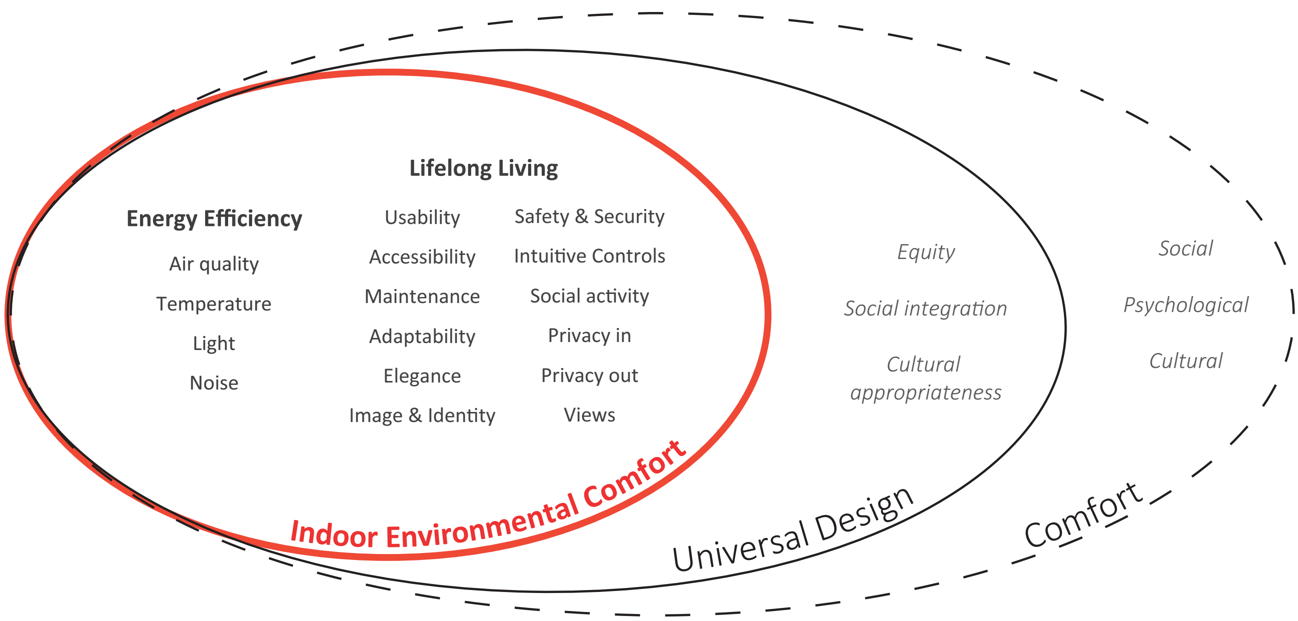

Figure 1. IEC framework and indicators.

It has been adopted in a variety of disciplines and has undergone several adaptations since then (Su et al., 2015). For the purposes of the CT, the various versions and adaptations of P–E Fit are less relevant than the fundamental conceptual model.

The basis of all versions of P–E Fit theory rests on two interacting elements, one human and the other contextual, each with their own characteristics, and the level of congruence between the two determines their fit to each other. In the context of the home, the two interacting parties are the resident and the indoor environment. This implies that if either of the two variables change, then the resulting fit should also change. In other words, the same person would experience a different fit in different environments, and, conversely, different people would experience a different fit in the same environment.

The CT queries both the *resident's preferences* and the *subjective performance* of the indoor environment in the home according to that resident. The fit between the resident's needs and desires and the performance of the indoor environment is what can be termed the comfort fit (CF).

The CT is not alone in using the P–E Fit as a basis. Steinfeld's ideogram "The Enabler" (Steinfeld et al., 1979) was the first to conceptualize disability as something relating to both the person and the building. It charts 188 environmental features which must be assessed against 15 (dis)abilities of a person, producing a "fit." The idea has become a key reference in occupational therapy research and was the basis for Iwarsson's (1999) "Housing Enabler" accessibility assessment method. Both tools need trained assessors to be carried out and are focused on accessibility and as such they present limitations in relation to the CT's intent of including also EE-related indicators. Unlike the "Housing Enabler" which results in a standardized assessment (regardless of the assessor or inhabitant), the original "Enabler" is dependent on the person using the building, i.e., the assessment is personalized. The CT follows this initial approach.

The study of P–E Fit is somewhat similar to studies of residential satisfaction, and some consider the P–E Fit as a key component of residential satisfaction (Kahana et al., 2003). Research on residential satisfaction, like P–E Fit, separates the residential environment from the resident and thus presents the same issues with the dynamic relationship between the two. However, asking separately the same user for the importance *and* the perceived performance of an indicator still offers some important advantages over simply asking about their satisfaction with an indicator. Firstly, studying the two parts of a concept offers more information than studying only the result—higher data resolution. Secondly, not asking directly about satisfaction avoids the social desirability problem with the concept of satisfaction which can lead to overstating (Amérigo & Aragonés, 1997). In addition, it provides conceptual clarity. Satisfaction has general connotations that apply to a more global, aggregate, rather than a specific indicator of indoor environment. Amérigo and Aragonés (1997) argue that indirect methods of asking about satisfaction are superior, despite their validity disadvantage.

Bringing together the view of comfort in the indoor environment as a product that can only be measured in a subjective and relative sense with the CF, it follows that the impact of a renovation is shown by the ΔCF, i.e., by the difference in fit between before and after renovation.

3. Comfort Tool Development and Methodology

Conceptually, the CT has two self-contained but connected parts: the CF assessment and the link with professionals. The comfort assessment method represents the main theoretical contribution of this article. It can be done digitally or by pen and article, with or without a building professional present. However, the resulting comfort profile is better suited to a digital tool to provide immediate feedback to users. Therefore, the CT is envisioned as a website or a digital application. Sections 3 and 4 concern the development of such a tool based on the theoretical principles described above.

3.1. Indoor Environmental Comfort Indicators

The IEC indicators used in the CT are a list of 16 distinct but overlapping and interacting aspects. The 16 indicators were developed through an iterative process of qualitative and quantitative studies. Initially, 21 comfort indicators were distilled from three qualitative studies which asked various groups to describe comfort at home in their own words (Kapedani, Herssens, & Verbeeck, 2017). Then, the results from a survey on comfort indicators (Kapedani, Herssens, Nuyts, & Verbeeck, 2017), the outcome from case studies on passive houses with lifelong living measures (Kapedani et al., 2019), and insights from literature research (see also Section 1.1) were used to fine-tune the list of indicators. Through this process, the list of IEC criteria was gradually distilled from an initially proposed 21 to the current 16. For example, the indicator "artificial light" was eliminated because it was important to only one in 10 people according to the results of the survey (Kapedani, Herssens, Nuyts, & Verbeeck, 2017). Based on feedback from expert participants in the Mutatie+ Living Lab project (Mutatie+, 2018), which was used for testing the IEC framework, the indicators of "safety" and "security" were merged under "safety" since people often used them interchangeably (especially in Dutch) and found the distinction confusing. A similar argument is made by experts, neighbours of the Pilot 2 house project, and colleagues regarding the indicators "adaptability" and "flexibility," and so these are also merged in a common indicator.

Some of the indicators are well understood and directly measurable (at least in theory) such as thermal comfort, noise, and air quality, while others are much more difficult to measure or even define (such as adaptability, elegance, and privacy). Ultimately, the tool relies on a subjective understanding of these indicators, and as consequence on a subjective understanding of comfort. This is purposely done. It is by directing, rather than prescribing these understandings of comfort that the CT works towards its aforementioned goals and reaches a personalized result that is meaningful to each particular user. Providing some kind of standardized and precisely measurable definitions for the IEC indicators could lead to conceptual pitfalls regarding their subjective perception. Gann et al. (2003) reported this difficulty with indicators describing architectural design quality. Discussions around the Fanger (1970) equation and the adaptive comfort model (de Dear & Brager, 1998; Nicol & Humphreys, 2002), which takes into account that people do adapt to their environment, reveal that it is an issue even in engineering-minded IEQ research. More importantly, such standardized definitions would be counterproductive in the drive for an individually relevant and aspirational definition of comfort.

3.2. Feedback and Revisions

The CT has been in development since Spring 2017 when previous theoretical work was used to offer a practical solution for measuring the impact of EE and lifelong living renovation in a pilot project of the Mutatie+ Living Lab, in Belgium, in which three social houses were renovated.

The tool has been continuously fine-tuned based on feedback from several sources until 2019. The partners of Mutatie+, which include experts in lifelong living, EE, and construction techniques, have been involved in a general feedback meeting and a live test of the tool on their Pilot 2 project. The CT was also used with neighbors living around the Pilot 2 house.

Colleagues, most of whom trained as architects, were asked for feedback on three separate occasions. They were first asked in a focus group setting to comment on the list of indicators and the structure of the tool. A few weeks later they were asked to test a limited paper-based version of it with the Mutatie+ Pilot 2 project as a case study. Five months after that, they were asked a final time to comment in a focus group setting after using a functional online version of the tool using their own homes as case studies.

The feedback has been recorded and, after careful consideration to maintain the tool's theoretical integrity and focus on its objectives, the feedback has been incorporated into the tool proposed here.

4. Comfort Tool Design

4.1. The Four Steps in the Comfort Tool Process

Based on the theoretical foundations described above, the CT is designed in four distinct consecutive steps (Figure 2). We first outline the four steps that are part of a full process in the CT. Each step is further detailed in the following sections. First, residents' needs and desires, i.e., their preferences, are queried using the list of comfort indicators. Then the perceived performance of the house on each of the indicators of IEC is gathered. From these two parts of information, a CF for each indicator is calculated in the third step. As part of this step, the improvement potential (IP)—the amount of unrealized CF—is introduced. The last step provides basic information on each comfort indicator and links to experts.

After the renovation, residents can re-evaluate their home in step two and a new CF will be calculated in step three. They can then compare their CF scores before and after the renovation to see an explicit analysis of the impact of the renovation measures implemented. The comparison reveals the ΔCF which is in line with the idea of comfort as a relative concept.

4.2. Preferences and House Evaluation

Residents' preferences and their evaluation of the home's performance are gathered with short questionnaires. First, users are asked to indicate how important each indicator is to them in making a comfortable home. A Likert scale of 1 to 5 is used where 1 means "not important" and 5 means "very important." When evaluating the home, users are asked to rate how well the home currently performs on each indicator. These are the same comfort indicators used for the user's preferences and a similar Likert five-point scale is used. In this

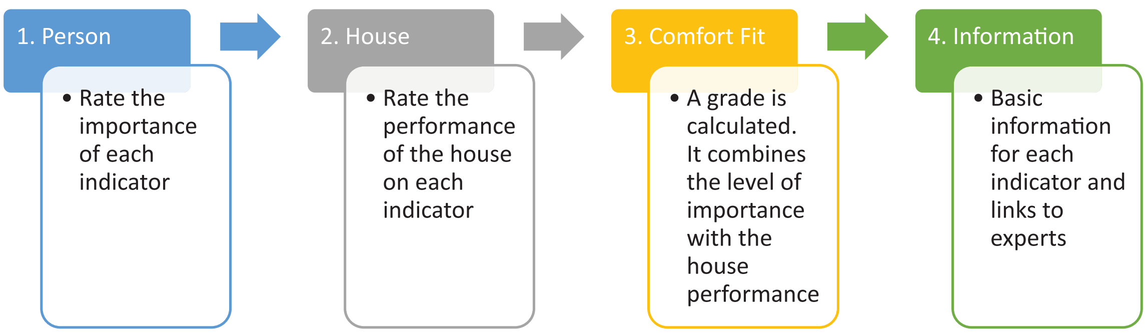

Figure 2. The four steps in the CT process.

case, a 1 means the home performs "badly," while a 5 means it performs "excellently."

A five-point scale was selected over more nuanced scales of seven or nine categories because it would be easier for people to differentiate between each of the five categories of importance (not at all important, not so important, somewhat important, important, very important). Therefore, the results would be coarser but more accurate.

The scores of importance and performance are used to calculate the CF between the home and the resident for each indicator.

4.3. Comfort Fit and Improvement Potential: Calculation and Presentation

The "comfort profile" is what can be called the result or output of the CT. Its calculation and presentation are important innovations of the instrument. The comfort profile shows the IP and the CF on each comfort indicator for the particular user in his or her particular dwelling.

The CF should not be misunderstood as simply the rating of the house's perceived performance by the resident entered in step two. This would ignore the other half of the P–E Fit theory, namely the personal preferences. The CF is a value that combines the performance of the indicator with how important that indicator is to the user. The simple performance rating does not tell us much about the potential impact of any improvements to the indicator, which is the central purpose of the CT.

The comfort profile needs to show how much more can comfort be improved towards an ideal fit—the IP. IP is a positive framing of the perceived shortcomings and expectations of the house in order to stimulate the tool users towards aspirational action.

When the house performance (HP) on a certain indicator is scored as "excellent" (five points), that implies that this indicator cannot, or at least does not need any improvement from the perspective of the homeowner. If it is however rated as performing "very badly" (one point), it implies that the indicator can be improved by up to four points (5 − 1 = 4).

This still only considers the "environment" part of the P–E Fit and does not take into account the person's preferences. The importance (I) of each indicator to the person is therefore introduced as a weighing factor ranging from one to five which moderates the value of any improvements to the house. Thus,

$$CF = HP \times I \tag{1}$$

The lowest score in the scale is set as one, rather than zero, to show that even an improvement that is peripheral to the needs of the residents still has some (although minor) value for them. If a value of zero was allowed, according to the CF formula (equation 1), the value of a significant improvement of an indicator rated as "not at all important" would be zero, which would not accurately reflect reality. The maximal possible fit would be:

$$HP_{max} \times I_{max} = 5 \times 5 = 25 \tag{2}$$

It can be shown that this maximal fit consists of three components (see Supplementary File):

$$\begin{aligned} \text{Maximal Fit} = {} & \text{CF} + [\text{IP if the importance of the indicator does not change for the person}] + \\ & [\text{IP if the importance of the indicator increases for the person}] \\ \Leftrightarrow {} & \text{MaxFit} = \text{CF} + \text{IP}_{house} + \text{IP}_{person\ change} \end{aligned} \tag{3}$$

The goal of the tool is to show how the building can be improved for the person, and not to change the person's ideas about what is/is not important. Hence, the CT will focus on the IP of the house, which is the gap between the ideal performance and the current performance of the house, multiplied by the importance:

$$IP = (HP_{max} - HP_1) \times I_1 \tag{4}$$

The indicators are presented in the comfort profile, a horizontal bar chart (Figure 3), the left-hand side of which is the MinFit = 1, and the right-hand side is the maximum MaxFit = 25. Each indicator is calculated and displayed separately. They are ordered with the indicators that have the highest IP of the house at the top in order to bring them to the viewer's attention. As explained in Section 2.2, absolute values of comfort have little meaning. Therefore, a conscious decision was made to remove numbers from the visualization to avoid creating senseless interpretations. the comfort profile's interpretation is based on an intuitive understanding of magnitude: "a lot," "a little," "more," or "less."

The elements described above are represented in different colors for clarity. Yellow represents the IP of the house. The more yellow there is in an indicator's bar, the more potential for renovation measures to improve the perceived performance of that indicator. The other part of the bar, colored blue or green, is the sum of the CF and the IP if the importance of the indicator increases for the person. These two could be represented separately, but especially the concept of "IP if the importance of the indicator increases for the person" is hard to explain intuitively to laymen. To avoid complexity without increased insight of the target audience, they are grouped and presented as "a part of comfort that can be hardly improved in the present situation." This we can call CF extended (ComfortFit^{ext}), although in the online tool, which is aimed at a non-academic audience, it is simply called CF.

The yellow bar, the IP of the house, can be small due to the small importance of the indicator (see Supplementary File). Thus, the other part, the ComfortFit^{ext}, can be large even if the rated performance of the indicator is low. The ComfortFit^{ext} is colored green except when the rated performance of the indicator is very low (rated 1 out of 5), in which case it is colored blue. This is done to say that the indicator may need attention even if the IP with the present importance is low.

Such is the case of "accessibility" in the hypothetical comfort profile in Figure 3. For example, if we suppose that a user has indicated that accessibility is "not important" (I = 1) and the house performs "badly" (HP = 1), on a Likert scale of 1 to 5, then the IP is:

$$IP = (HP_{max} - HP_1) \times I_1 = (5 - 1) \times 1 = 4$$

And ComfortFit^{ext} would be:

$$ComfortFit^{ext} = 25 - 4 = 21$$

Therefore, a low HP coupled with low importance can give a low IP and high ComfortFit^{ext} score.

As mentioned in Section 4.1, residents can reevaluate their homes after the renovation has been completed. A new comfort profile is calculated using the new rating of the home performance and the same importance scores given before the renovation. The comfort profiles before and after the renovation are presented side by side (Figure 4). In this manner, the difference in CF is not displayed as a value but made apparent visually. This encourages a more intuitive rather than precise understanding by the viewer of the impact of renovations on their perceived comfort. Unlike the individually presented comfort profiles, in the comparison, the comfort indicators are ordered alphabetically.

4.4. Linking With Experts

The final step in the process is not about the IEC assessment but is an important step for the initial motivation of developing the CT: to improve awareness and communication in order to increase adoption of EE and lifelong living measures. Thus, the CT can bridge the gap from dreaming to realization by making it easier for people to connect with experts who would provide personalized advice on how to improve each comfort indicator that is shown to have a high potential for improvement in their home.

Each comfort indicator is connected with a dedicated set of information that provides basic descriptions about the indicator and suggestions of external experts and recognized sources of knowledge on the topic. Due to the widely varied nature of home renovations, the information is intended as a springboard to contact experts who can give more personalized and therefore more relevant advice. It is also not intended as a repository of knowledge on any of the topics. Many such repositories, networks, and tools already exist. The CT intends to simply guide users to that knowledge, framed as a direct answer to their needs/desires for improvement rather than as top-down general advice on how to renovate. It is out-

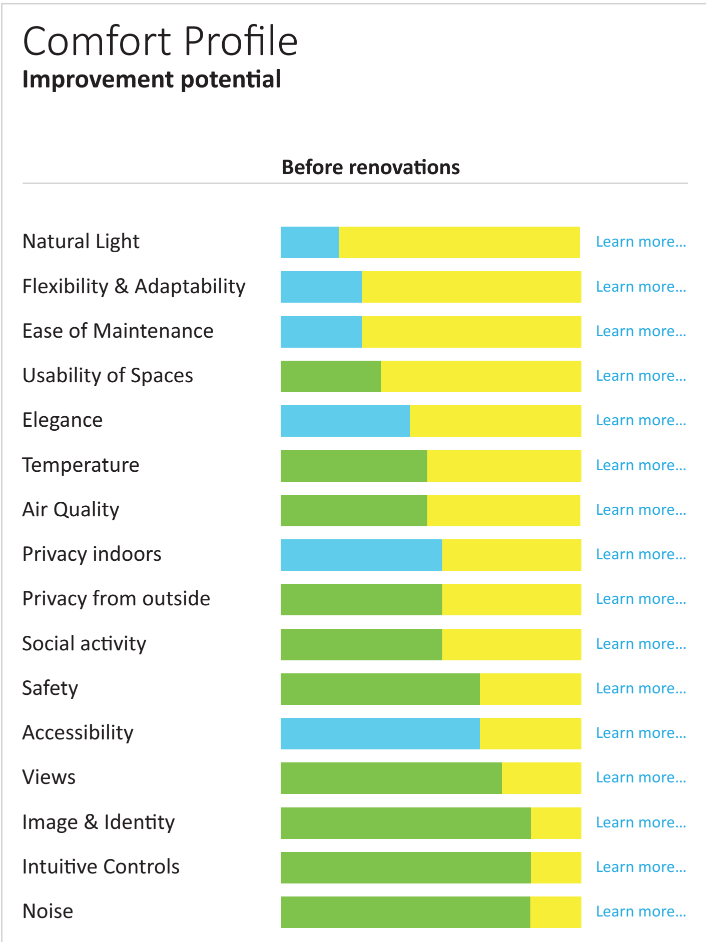

Figure 3. Example of the comfort profile before renovation visualizing ComfortFit^{ext} and the IP.

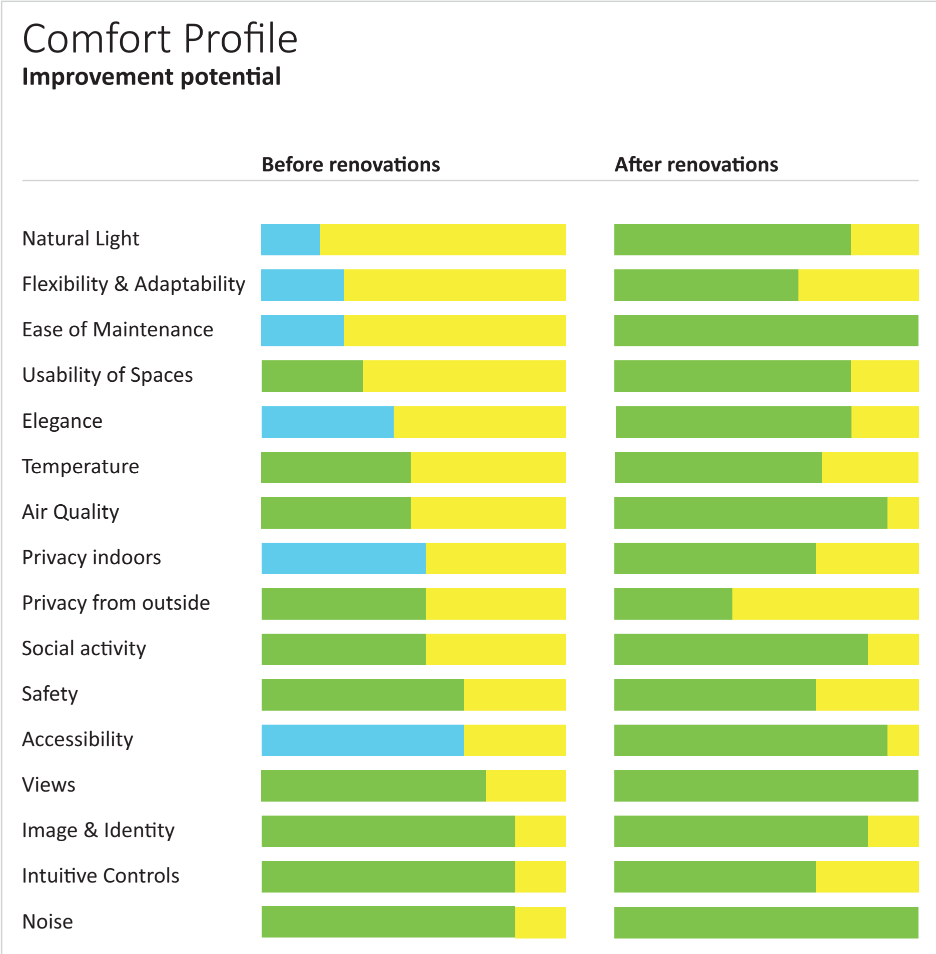

Figure 4. Comparison of comfort profiles before and after renovation.

side the scope of this research to design the way this information is conveyed.

5. Discussion and Conclusions

The CT is first and foremost a tool for thinking, starting, and expanding the discussion between homeowners and building professionals about renovation measures towards the deeper and longer-term needs and desires. The CT relies on a subjectively understood concept of comfort. This makes its results difficult to turn into a standardized assessment or to aggregate and generalize into something like policy guidelines. However, this is not its goal. It is its subjective nature that can make it more relevant to people and link aspirational ideas of renovation with otherwise boring or even depressing discussions about insulation or wheelchair-accessible bathrooms.

The CT also does not directly provide answers or designs for improving comfort indicators. Although it guides users towards information on EE and lifelong living, it cannot guarantee that this will lead to more of those measures. The CT relies on the principled knowledge, wisdom, and experience of designers and other experts to provide sustainable solutions for homeowners. In other words, the instrument does not aim to replace architects, but rather it acknowledges their crucial roles in shaping the kind of solutions that are ultimately adopted and offers assistance in this regard. The CT also acknowledges the crucial role of the homeowners in a home renovation as final decision-makers.

The CT has a structural focus on the individual preferences of inhabitants who are often both decision-makers and not sophisticated in terms of building knowledge. This means that the CT is best suited to single-family home applications. It is not directly applicable to large projects with sophisticated clients and large numbers of varying users such as public buildings, or speculative housing developments where the decision-making client is not a resident and has interests other than the long-term comfort of the residents.

The CT method requires further field testing and refinement. The underlying theoretical principles described in Section 2 and the introduced concepts of CF and IP (Section 4) make for a flexible foundation of the CT method allowing for further revisions, expansions in scope, and a variety of different applications.

One area for further exploration, suggested by some Mutatie+ experts, would be to expand the target group of the CT to include people looking to rent or buy a new home. In this scenario, instead of comparing a home before and after renovation, the tool shows the differences in comfort between the new prospective home (to buy or rent) and the current home, always starting from the needs and desires of the residents. In such a scenario, the CT could be used to visualize the additional value of homes with integrated EE and lifelong living measures, providing another incentive for their adoption.

Another possible use for the CT, in practice, is by building professionals such as architects, builders, and real estate agents to better understand the needs and desires of their clients and to judge how well they have met them. It can be used as a reference for discussions throughout the design, construction, or property searching process. In a similar vein, research questions can be asked about policy assertions that deep energy renovations lead to higher comfort and the CT can be used to assess the actual impact of these deep renovations on the perceived IEC of residents.

In education, the CT can be used as a teaching aid in architectural design studios to expand the scope of design and avoid tendencies to narrowly focus on aesthetics. This approach brings into high relief the wide range of needs and desires a design must consider and the balancing act that a designer needs to perform. In addition, the CT can be used to highlight the relevance of or put into practice knowledge from technical courses on building physics and accessibility by placing them in a context of aspirational comfort—the same characteristics that make the CT meaningful to homeowners.

In sum, the CT is an instrument that takes into account both EE and UD when pointing out aspects of the home in need of improvement from the perspective of the homeowner. It serves as a tool for thinking and a starting point for an informed discussion between homeowners and building professionals. The CT can be used variously in practice, research, and education applications related to architectural design and decision-making in sustainable home renovations.

Conflict of Interests

The authors declare no conflict of interests.

Supplementary Material

Supplementary material for this article is available online in the format provided by the authors (unedited).

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Article

Concerns of Owner-Occupants in Realising the Aims of Energy Transition

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Abstract
Although there is an array of technical solutions available for retrofitting the building stock, the uptake of these by owner-occupants in home improvement activities is lagging. Energy performance improvement is not included in maintenance, redecoration, and/or upgrading activities on a scale necessary to achieve the CO_2 reduction aimed for in the built environment. Owner-occupants usually adapt their homes in response to everyday concerns, such as having enough space available, increasing comfort levels, or adjusting arrangements to future-proof their living conditions. Home energy improvements should be offered accordingly. Retrofit providers typically offer energy efficiency strategies and/or options for renewable energy generation only and tend to gloss over home comfort and homemaking as key considerations in decision-making for home energy improvement. In fact, retrofit providers struggle with the tension between customisation requirements from private homeowners and demand aggregation to streamline their supply chains and upscale their retrofit projects. Customer satisfaction is studied in three different Dutch approaches to retrofit owner-occupied dwellings to increase energy efficiency. For the analysis, a customer satisfaction framework is used that makes a distinction between satisfiers, dissatisfiers, criticals, and neutrals. This framework makes it possible to identify and structure different relevant factors from the perspective of owner-occupants, allows visualising gaps with the professional perspective, and can assist to improve current propositions.

Keywords
built environment; customer satisfaction; energy efficiency; energy transition; owner-occupants

Issue
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1. Introduction

Since the built environment is one of the main emitters of CO_2 globally, a substantial impact can be expected from large scale implementation of energy-efficiency measures in the form of building retrofitting and the substitution of fossil fuels for renewable energy sources (International Energy Agency, 2017; Lucon et al., 2014; Sandberg et al., 2021). To get these implemented, large scale retrofitting programmes and renewable energy generation plans have been developed. Additionally, smooth customer journeys and neighbourhood approaches are being created (Bader et al., in press). Although there is a wide array of technical solutions available to improve the energy efficiency of the built environment and to generate renewable energy for heat and power, the uptake of these solutions by owner-occupants is lagging (Brouwer, 2019; House of Representatives of the States General, 2019; Netherlands Environmental Agency, 2019). It is suggested that these programmes are too closely focused on the optimisation of technology and economic factors (Bergman & Foxon, 2020). Energy performance improvement is not included in maintenance, redecoration, and/or upgrading activities of owner-occupants on a scale necessary to achieve the CO_2 reduction aimed for.

Owner-occupants usually adapt their homes in response to everyday concerns, such as having enough space available or adjusting arrangements to future-proof their living conditions (Joint Centre for Housing Studies, 2009). Research shows that renovation intentions usually emerge from specific conditions in domestic life (Wilson et al., 2015) in which energy efficiency has a minor role at most. According to Wilson et al. (2015), efficiency measures should be bundled into broader types of retrofitting and home improvements, and incentives should target the underlying reasons why homeowners decide to retrofit in the first place. Retrofit providers typically offer energy-efficiency strategies and/or options for renewable energy generation only and tend to gloss over home comfort and homemaking as key considerations in the decision-making for home energy improvement. In fact, retrofit providers struggle with the tension between customisation requirements from private homeowners and demand aggregation to streamline their supply chains and upscale their retrofit projects (Oostra & Been, 2016). To get a better understanding of consumer satisfaction of owner-occupants concerning energy retrofit, this article will zoom in on concrete experiences from Dutch practices.

From marketing theory, it is known that it is very important to address needs fulfilment in combination with customer satisfaction (Dowling, 2002; Giese & Cote, 2000; Klasens & Oostra, 2016; Kotler & Armstrong, 2017). In management literature, customer satisfaction is considered important because of its role in creating competitive advantage (e.g., Kotler & Armstrong, 2017; Matzler & Hinterhuber, 1998; Mittal et al., 2005). Therefore, it seems fair to conclude that insight into customer satisfaction during the customer journey of energy retrofit projects is important to be able to increase the number of households interested in energy-efficiency measures. In this article, the following hypotheses are therefore tested: A customer satisfaction framework can help to (a) identify and structure factors in customer journeys of energy retrofits, (b) visualise gaps between the owner-occupants' perspective and the take professionals have on propositions, and (c) provide us with insights on how current propositions can be improved. Before the case studies are introduced, the conceptual framework on consumer satisfaction is presented.

2. Customer Satisfaction: On Dissatisfiers, Satisfiers, Criticals, and Neutrals

Most satisfaction research concentrates on confirmation and/or disconfirmation of a pre-consumption standard responsible for satisfaction and dissatisfaction (Oliver, 2015). Several additional determinants of satisfaction have also been linked to satisfaction (Heitmann et al., 2007), such as perceived equity, product quality, post-decision regret, consumption-related emotion, and need fulfilment. In his seminal work on customer satisfaction, Oliver (2015) distinguishes three important approaches: the desires, expectations, and needs approach. In this research, the needs approach has been used. Needs are mostly aligned with the fulfilment of deficits, as are most services like home repair, health care, and legal redress (Oliver, 2015). There are two dominant needs theories: Maslow's theory and Herzberg's theory. Maslow's theory is discarded since it raises several issues which make it difficult to apply it in a marketing context. Herzberg's theory, in contrast, is presented as useful (Oliver, 2015). Theorising about satisfiers and dissatisfiers dates back to the days when human resources management emerged as part of management theory. Herzberg et al. (1959) were studying the working conditions in factories and discovered motivators and hygiene factors, which would later lead to the motivator-hygiene model or the two-factor theory. Hygiene factors are conditions workers consider to be self-evident, like safety measures, physiological conditions (e.g., lighting, temperature, noise levels). Motivators, in contrast, are factors that increase personal satisfaction and motivation to increase production. While their presence increases motivation, their absence does not cause dissatisfaction.

Other researchers built on these results, extending theory formation on the topic of job satisfaction (e.g., Soliman, 1970; Wolf, 1970). Later, these ideas were adopted in marketing when analysing and evaluating the satisfaction of customer products (e.g., Maddox, 1981; Oliver, 1995; Swan & Combs, 1976), engineering (e.g., Kano et al., 1984; Matzler & Hinterhuber, 1998), service industries (e.g., Brandt, 1988; Cadotte & Turgeon, 1988; Silvestro & Johnston, 1990), and website design (e.g., Holloway & Beatty, 2008; Zhang & von Dran, 2000). Several terms are used to refer to the different antecedents of dissatisfaction and satisfaction (see Supplementary Material). In this study, we adopt the terminology of Cadotte and Turgeon (1988):

- Dissatisfiers: Factors that can cause dissatisfaction but will not increase satisfaction when addressed. These usually relate to the minimum requirements concerning functional performance and the extrinsic needs of customers. If a gap occurs towards customers' perception, this can result in complaints.
- Satisfiers: Factors that increase satisfaction but do not increase dissatisfaction while not included. If these factors exceed customer expectations, it might lead to a compliment. Satisfiers will stimulate customers to come into action.
- Criticals: Factors that impact both satisfaction and dissatisfaction. Examples include the organisation of information.
- Neutrals: Factors with no impact on both satisfaction and dissatisfaction. Although not mentioned by Cadotte and Turgeon (1988), the authors will use this category to identify factors that are essential in the eyes of professionals but causes no dissatisfaction or satisfaction of owner-occupants.

Satisfaction and dissatisfaction are not to be considered as two extremes on one scale (Kano et al., 1984). They have separate scales (see Figure 1): unfulfilled or fulfilled satisfaction factors vs. addressed or not addressed dissatisfaction factors.

The scientific community is still debating on the exact definitions of consumer satisfaction (Souca, 2014). Although the concept of consumer satisfaction is still not fully understood, and a standard form of measurement is lacking (Souca, 2014), it has proven helpful in a wide array of sectors, e.g., sports products, cosmetics, durable products, food products, web pages, hotel bookings, health care, and bank services (for more, see Oliver, 2015; Souca, 2014; Vargo et al., 2007). The authors could not find studies evaluating the energy retrofitting of dwellings, although there is a study that evaluates retrofitting of shopping centres (Haase et al., 2015). The term "customer satisfaction" is also used concerning the quality evaluation of builders (e.g., J. D. Power, 2020; Klantgericht Bouwen, 2021). When using this model in the context of energy-efficient retrofitting, the following insights from research in other sectors can be of value: First, the category to which a factor belongs is not static. Over time, product attributes that once were satisfiers tended to become criticals, and eventually dissatisfiers (Brandt, 1988; Cadotte & Turgeon, 1988; Kano et al., 1984). Second, in a study by Maddox (1981) on clothing, personal care, and durables, it was discovered that findings in one industry can differ from another, indicating that findings are, therefore, context-specific. Third, the behavioural economics research of Kahneman and Tversky (1979) suggests that loss aversion concerning dissatisfiers outweighs the impact of satisfiers. Giese and Cote (2000) noted that customer feedback is stronger concerning dissatisfiers. Several satisfiers are necessary to compensate for one dissatisfier to make this strategy work at all. The implication is probably that dissatisfiers in the form of minimal functional requirements should be met first, for market pull to emerge. Dissatisfiers, therefore, seem to have priority over satisfiers (Vargo et al., 2007). Satisfiers, however, can also be used to create additional market pull. Finally, a warning is made not to remain focused on the physical aspects, attributes, and actions of products and services only. Attention should also be given to customer thinking (Oliver, 2015). Most technical specifications and product features are irrelevant to most residents. The crux is to discover what factors within energy-efficient retrofitting do matter to make sure the propositions meet the minimum requirements and, additionally, to identify what factors can be used to make energy-efficient retrofitting more appealing.

3. Methodology

This section describes both case study selection and case study methodology. The analysis of the case studies is based on the framework of satisfiers, dissatisfiers, criticals, and neutrals presented in the previous section.

3.1. Case Study Selection

The Netherlands provides an interesting context for case studies on owner-occupied retrofitting due to a rather large percentage of owner-occupied housing (57.2%) in combination with a rather large social housing

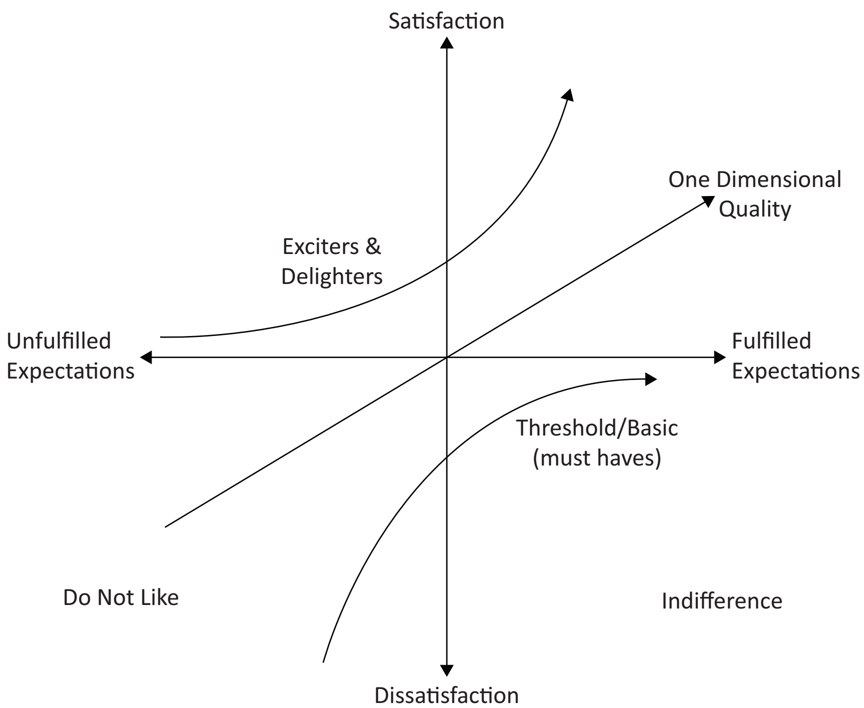

Figure 1. Kano's model. Source: Kano et al. (1984, p. 41).

sector of 29.1% (Housing Europe, 2021). The main focus of research aiming to further the retrofitting of residential buildings was first on housing associations and renters. The relatively large social rental sector in the Netherlands allowed firms to bundle individual dwellings into larger, commercially more attractive assignments. First, these solutions were applied in larger retrofit projects of social housing only. Later, some of these solutions also became available for individual owner-occupants. The three case studies selected used different instruments implemented to further the uptake of energy efficiency for private homeowners.

Energy Expedition Apeldoorn (#ENEXAP) was part of Energiesprong, a Dutch innovation programme commissioned by the Dutch Ministry of the Interior and operated by Platform31. The aim was to make various types of buildings zero-energy and to boost large-scale market initiatives. In the sub-programme Lokaal Alle Lichten Op Groen (LALOG), the owner-occupants were challenging professionals to help them make their homes zero-energy. It was a process of learning-by-doing by residents, builders, municipal officers, installation contractors, appraisers, and other professionals. The subsidised #ENEXAP project ran from January 2012 to December 2014. One of the authors, Mieke Oostra, was a member of the #ENEXAP board from November 2013 to April 2015.

The Duurzaam Thuis Twente (DTT), loosely translated as "Sustainable Home Twente," a cooperation of 14 municipalities focusing on the energy efficiency of owner-occupied dwellings, applied successfully for a grant of VNG (the association of Dutch municipalities), the VNG scheme for cooperating municipalities. DTT also applied for grants from the province, as well as additional funding from the municipalities part of DTT. The description of DTT is based on Mieke Oostra's experience as part of the initiative: She was a member of the DTT board from April 2016 to January 2020.

Verenigingen van Eigenaren (VvEs) is loosely translated as "association of owners." The 13 associations are based in the cities of Breda and 's-Hertogenbosch. Both cities have a subsidy programme in which VvEs are encouraged to draw up an energy plan. By Dutch law, someone who owns an apartment is automatically a member of the subsequent owner's association (VvE). The VvE looks after the joint interests of the owners of the apartments, like making sure the building is maintained, cleaned, and insured. Decisions in the VvE are taken democratically. A major challenge for VvEs is to make progress in energy efficiency. The process can be complicated because the owners must tackle this together. One of the authors, Nelleke Nelis, from the company Making Space, advised and guided the VvEs in drawing up a plan. She did this together with a cooperative of energy consultants, who all have specific expertise (financial, technical, legal, and process supervision).

3.2. Case Study Methodology

The three case studies were studied retrospectively. For these case studies, the following materials were available for a qualitative analysis using the theoretical framework presented in Section 2:

- #ENEXAP: Memos of board meetings (8); notes of residents' meetings (4); notes of meetings with one of the energy directors (3); notes of meetings with Energiesprong (2); report from Energiesprong (1); notes of study meetings for associated companies (5); notes (1), videos (4), and documents (3) from a meeting in which the propositions were scrutinised; impressions of a public event (1); and conversations with people related to #ENEXAP (3). The data used in this article is from October 2013 to June 2015.
- DTT: Notes of board meetings (30); notes of strategy meetings (2); notes on conversations with the organiser of owner-occupant meetings (2); notes of meetings with municipalities (3); study meeting for the companies (1); and conversations to reflect on the outcomes of DTT with people related to DTT (3). The data used in this article is from April 2016 to January 2020.
- VvEs: Notes of the board meetings with the VvEs (25); a residents' survey (1); and technical and financial analysis of all the VvEs involved (13). The data (see Table 1) used in this article is from January 2017 to September 2021.

To strengthen the validity of the data collected, the outcomes from the case study analyses were triangulated with (a) observations during the retrofit trajectories, (b) the evaluation studies from #ENEXAP (Oostra & Been, 2016) and DTT (Oostra & Bader, 2021) on the execution of the programme, as well as the outcomes, and (c) findings from the literature.

Table 1. Case study overview.

Case Study	#ENEXAP	DTT	VvEs
Type of dwellings	Row housing and detached housing	Row housing and detached housing	Multi-family housing
Amount of buildings	38	4,350	13
Households involved	38	4,350	612

4. Energy Expedition Apeldoorn (#ENEXAP)

In 2011, Apeldoorn saw the launch of #ENEXAP, a group of around 33 households interested in making their homes zero-energy. During the process, the group expanded to 38 households. The #ENEXAP team was founded with participants from local owner-occupants of businesses, civil society organisations, the municipality of Apeldoorn, and the local University of Applied Sciences (Saxion). The owner-occupants fuelled professionals with their ideas and wishes; professionals helped the owners make their wishes achievable.

The specific goal of the LALOG-subsidy was to put clients at the centre of the development of propositions of local companies to improve the energy efficiency of occupant-owned homes. These propositions should de-burden owner-occupants in increasing energy performance towards zero-energy. The planned result of this programme: 20 retrofitted dwellings. Secondary aims were many. Not only was a considerable reduction of the energy bill required, but also improvement of the overall comfort level, a healthier indoor climate, the application of environmentally friendly building products, and an increase of property value. During the programme, business cases for companies also had to be drawn up that would prove energy-efficient retrofits for private homeowners to be an interesting market niche.

In June 2015, after a process of roughly four years, five dwellings were well on their way to becoming zero-energy. Other households had started to save energy. Through all sorts of presentations, meetings, workshops, and excursions, both residents and professionals increased their knowledge levels considerably. For professionals, it was not always easy to keep up the pace, especially with the very involved retired occupant-owners with technical backgrounds. Owner-occupants were sharing experiences on the things they had implemented, like the use of LED lighting, the discontinuation of built-in kitchen boilers, the energy demands of waterbeds, and how to persuade teenagers to reduce their time in the shower. Three different consortia were polishing their propositions for owner-occupants (Oostra & Been, 2016). Dissatisfiers, satisfiers, criticals, and neutrals identified in the analysis of the material available can be found in Table 2.

5. Duurzaam Thuis Twente (DTT)

Fourteen municipalities in Twente, the eastern part of the Netherlands, decided to collaborate in their efforts to improve the energy efficiency of owner-occupied housing: Almelo, Borne, Dinkelland, Enschede, Haaksbergen, Hellendoorn, Hengelo, Hof van Twente, Losser, Oldenzaal, Rijssen-Holten, Tubbergen, Twenterand, and Wierden (see Figure 2). Their first joint action was the development of a media campaign promoting the uptake of energy-efficiency measures by owner-occupants. Several PR agencies were asked to pitch a media campaign concept. A consultant presented a plan to facilitate citizens in making their homes more sustainable based

Table 2. Dissatisfiers, satisfiers, criticals, and neutrals in the perception of owner-occupants involved in #ENEXAP.

Category of Assignment	Factor	Description
Dissatisfiers	Communication	Complaints were made about the time businesses took to prepare an offer, or that no follow-up was received when questioned.
	Lack of choice	The first group of three selected owner-occupants received an offer from three different consortia (April 24, 2014). They were disappointed to find that the consortia came up with a similar set of energy measures. They had hoped to receive alternative retrofit concepts.
	Demolition of recent improvement	For several households, it was necessary to take out the flooring to ameliorate the energy performance of the ground floor. When this turned out to be a recent home improvement, households preferred to skip this intervention.
Satisfiers	Home extension	One household just fell for the idea of adding a conservatory to the house as a way to improve energy efficiency. The idea was introduced by students of the TU Delft as a proof of concept for the Solar Decathlon, an American contest for student teams.
	Future-proofing of the home	One of the households was interested in energy-efficiency measures in combination with the future-proofing of their home. Unfortunately, the consortium considered the combination too complex.
	Direct feedback	With a plug-in set from #ENEXAP, residents could temporally measure the energy usage of different appliances. This direct feedback opened the eyes of owner-occupants for the impact, e.g., the built-in kitchen boiler, waterbed, or shower time had on their overall energy consumption.

Table 2. (Cont.) Dissatisfiers, satisfiers, criticals, and neutrals in the perception of owner-occupants involved in #ENEXAP.

Category of Assignment	Factor	Description
Criticals	Comfort improvement	Energy-efficient retrofitting was being promoted with the advantage of improved comfort levels. Consequently, this is what residents expected. When problems with draft and cold traps occurred after retrofitting the owner-occupants turned out to be disappointed.
	Reduction of the energy bill	Complaints were made when the energy bill did not reduce, at least not as much as expected. The residents suspected the supplier was unqualified or, worse, that they were being cheated.
	Financial loan	Several households indicated the availability of financial loans as important.
	Advice report	Much time and effort had been spent into the assignment of elaborated reports from energy advisors (EPA Super Luxurious). The contractors never seemed to take the outcomes of the reports into consideration.
	Performance guarantee	Owner-occupants indicated valuing a performance guarantee from the consortia. In practice, however, no one actually paid the additional sum to secure the guarantee. The simple fact that the consortium dared to offer a performance guarantee functioned as a proof of quality in the perception of owner-occupants.
Neutrals	Coaching and training of the firms	For the companies, this was essential. For the clients, this was not relevant.

on insights from consumer marketing, not the anticipated plan for a media campaign. This was the route the municipalities decided to take. Other stakeholders of DTT were owner-occupants, coaches, companies and consortia, communication office, Pioneering (local innovation network in construction), the VNG, and other supporting organisations (e.g., Bouwend Nederland, Techniek Nederland; Oostra & Bader, 2021).

An approach was drafted and executed to support owner-occupants in making their homes more energy-efficient. A network of energy coaches was to be created, and, additionally, a network of companies able to take on the work. This eventually led to the start of DTT in 2016. The themes were: improving comfort levels, energy-saving, future-proof living, retrofit and maintenance, energy generation, and preparation to disconnect from natural gas. Dissatisfiers, satisfiers, criticals, and neutrals identified in the analysis of the material available can be found in Table 3.

6. Owner Associations (VvEs)

In the period between 2017 and 2021, 13 VvEs started by drawing up an energy plan. The process always included a "do-it-yourself" survey of the residents. The themes were: residential data, usability of apartment building,

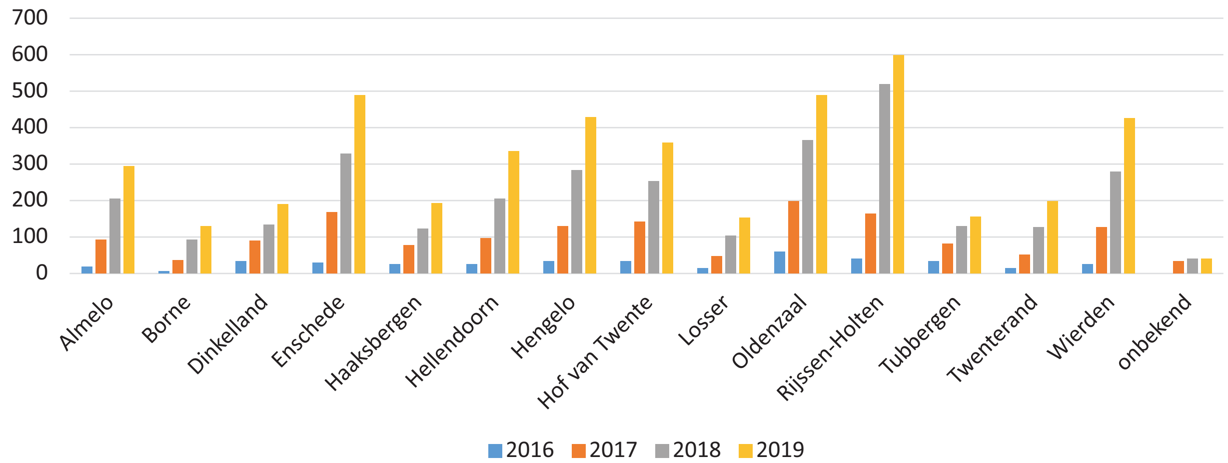

Figure 2. Cumulative amount of advice sessions booked by households in various municipalities of the Twente region. Source: DTT (2020).

Table 3. Dissatisfiers, satisfiers, criticals, and neutrals in the perception of owner-occupants involved in DTT.

Category of Assignment	Factor	Description
Dissatisfiers	Communications	Complaints, questions, and suggestions were made concerning information on energy-efficiency measures, subsidies, and/or events.
	Low quality of work	The work of the associated firms did not always meet the benchmark of owner-occupants.
Satisfiers	Future-proofing	A household member was developing difficulty walking and climbing stairs. The couple had the choice to move or to future-proof their home. They preferred to stay. An extension was made for a new wheelchair-friendly bathroom, while the insulation value of the façade was ameliorated at the same time. Additionally, the heating system was compartmentalised, which made it possible to only heat the rooms in use.
	Home extension	Another household wanted to extend their kitchen into the garden. The kitchen also got a new tile floor, underfloor heating, and floor insulation. Electrical cooking replaced natural gas cooking, as is common in the Netherlands.
	Subsidy	A household that did not expect to be eligible for a subsidy was pleasantly surprised to find out via DTT that they had. This extended their budget and, as a result, they could make a larger investment in energy efficiency than initially expected.
	Direct feedback	Direct feedback on what members of the household could do to reduce energy consumption by closing a door, switching off a radiator, or reducing time in the shower came as a surprise to most people. Thermography also proved a valuable feedback instrument when people were considering a retrofit. As a means to attract newcomers, this motivated a lot of new households to contact DTT. However, these new appointments did not result in more households taking energy measures.
Criticals	Comfort improvement	Extra comfort was welcomed. Discomfort was, however, sometimes experienced due to sitting next to a cold window after retrofitting, causing complaints.
	Reduction of the energy bill	A household in which the breadwinner became unemployed was looking for ways to lower the monthly payments. One of the options they saw was to reduce the energy bill. A folder informed them about the existence of DTT's energy coaches. The household was already considering generating their own electricity with solar panels, but they were also interested in infrared panels. After the advice, they decided to install 20 solar panels and not to opt for the infrared panels. Instead, they chose to purchase new radiators, which can be regulated to only provide heating when necessary.
	Energy coaches	Advice from the independent energy coaches was highly appreciated by owner-occupants. The coaches provided advice on behavioural aspects (e.g., closing of internal doors), available subsidies in combination with advice on insulation, heat pumps, solar panels, LED lighting, etc. This helped people to structure the available information and to draw up a concrete plan for their homes. Not every energy coach was an asset. A specific coach criticised measures owner-occupants had taken in the past, which resulted in complaints.
Neutrals	—	—

safety and security, health and comfort, and complaints and wishes of residents. These surveys were carried out together with the VvE board. The survey ensured that all residents were involved in the advice process from the start. The average response was about 70%. The survey was followed by energy advice with both a step-by-step plan and a total approach. The retrofitting processes of all 13 VvEs are still in progress. Dissatisfiers, satisfiers, criticals, and neutrals identified so far can be found in Table 4.

7. Analysis

In this section, the combined outcomes of the three analyses are described, using the four categories: dissatisfiers,

Table 4. Dissatisfiers, satisfiers, criticals, and neutrals in the perception of owner-occupants involved in VvEs.

Category of Assignment	Factor	Description
Dissatisfiers	Low quality of work	Many maintenance solutions appeared to be of low quality, were poorly monitored during execution, and, as a result, new repair work was required. The VvE board usually consists of volunteers with little or no technical knowledge. They expected a professional approach from their contractors but were often disappointed by the quality of the work.
Satisfiers	Beautification	The residents considered the appearance of their property to be very important. The option for a new façade made them feel proud and would also have positive effects on the resale value of their apartments. A new, energy-efficient façade was, therefore, an interesting offer for most apartment owners.
Criticals	Generation of funding for retrofitting	The idea for the possible addition of an extra layer of apartments on top of the block was appealing to the owner-occupants since it would generate part of the budget needed for retrofitting. However, this brought all sorts of additional questions to the table that required additional time and effort of the board, especially regarding the feasibility of the idea. This caused mixed feelings.
Neutrals	Fire-safety	Occupants were rarely aware of the importance of fire safety. Additionally, the (ageing) population of the building might require additional measures to be able to evacuate everyone in case of an emergency.
	Ventilation	Most ventilation systems were functioning poorly. Occupants proved not to be aware of the related health risks. In practice, it was very difficult to convince residents that measures were necessary.
	Multi-year maintenance planning	Owners' associations are obliged to draw up a multi-year maintenance plan. These must be renewed every five years. Energy-saving measures are not a standard part of this planning.

satisfiers, criticals, and neutrals. The outcomes of the different case studies are displayed in Table 5.

7.1. Dissatisfiers

Four specific factors appeared in the category of dissatisfiers: communication, low quality of work, demolition of recent home improvement, and lack of choice. The factor of communication does not come as a surprise. This matches with findings in other sectors. Another dissatisfier was the suggestion to take out a rather new tile or wooden floor to improve the energy performance of the ground floor. In these cases, floor insulation was simply skipped. The quality of maintenance work or how architectural details were dealt with was another factor that appeared in this category. The ornaments in woodwork, additional corners, and stained-glass windows, all part of the authentic look and feel of dwellings, can be devalued during a retrofit (DTT). Finally, owner-occupants seem to expect to have a choice between several alternatives. Within #ENEXAP, several owner-occupants made explicit that one proposition only led to disappointment.

7.2. Satisfiers

In the category of satisfiers, the following factors emerged: adding an extension, future-proofing, receiving an unexpected subsidy, direct feedback, and beautification. The residents considered the appearance of their property to be very important. A makeover with a new energy-efficient façade in combination with an expected increase of resale value proved to be an interesting offer for most apartment owners (VvEs). Some households responded very enthusiastically concerning the possibility of an energy-efficient retrofit in combination with an extension (conservatory or kitchen), or energy reduction as a package deal with future-proofing. These households were strong advocates of these ideas to convince the consortia to prepare this interesting proposition. The moment it became clear the consortia would not come with such an offer, these households lost interest. Direct feedback helped to raise awareness but turned out not to be a guarantee for action (DTT).

7.3. Criticals

Financial loans and a performance guarantee appeared in the category of criticals, as well as possible advice from energy coaches, the possibility to generate additional funding for the retrofit, comfort improvement, and reduction of the energy bill. The reason for requesting a performance guarantee might be that, generally, expectations of the construction sector are not very high. The factors of comfort improvement and reduction of the

Table 5. Dissatisfiers, satisfiers, criticals, and neutrals in the perception of owner-occupants.

Category of Assignment	Factors in #ENEXAP	Factors in DTT	Factors in Owner Associations
Dissatisfiers	Communication	Communication	Low quality of work
	Lack of choice	Low quality of work	
	Demolition of recent home improvement		
Satisfiers	Home extension	Future-proofing	Beautification
	Future-proofing	Home extension	
	Direct feedback	Subsidy	
		Direct feedback	
Criticals	Comfort improvement	Comfort improvement	Generation of funding for retrofitting
	Reduction of the energy bill	Reduction of the energy bill	
	Financial loan	Energy coaches	
	Performance guarantee		
Neutrals	Advice report		Ventilation
	Coaching and training of the firms		Fire-safety
			Multi-year maintenance planning

energy bill are directly related to the arguments often used to convince people to invest in energy-efficiency measures. These promises probably led to a rise of the expectations owner-occupants had concerning the performance level, hence the fact they are considered criticals. Without presenting them as a benefit, these factors likely belonged to the category of dissatisfiers. In that situation, they would only lead to complaints in case of malfunction. The possibility to generate funding for the required retrofit with the creation of extra apartments left the owner-occupants with many unanswered questions. This caused people to have both feelings of satisfaction and dissatisfaction.

7.4. Neutrals

Easily overlooked by owner-occupants are the importance of ventilation, fire safety, the possibility to combine the implementation of energy-efficiency measures with maintenance, and the importance of the condition of the foundation, all in the category of neutrals. Also, the training and coaching of the firms are part of this category. In the eyes of customers, these factors are irrelevant and, therefore, part of the neutrals section. This neutral category, part of the theoretical framework, was deliberately framed to contain factors that are relevant for professionals, but not to owner-occupants. In practice, these factors sometimes led to friction. This manifested itself most clearly concerning ventilation. Most residents did not consider this as problematic. The residents in the VvE case presumed they could solve a lack of ventilation by opening a window. The pressing question that arises from this category of neutrals is how to create a context in energy retrofits in which professionals can address important technical issues without bothering the owner-occupants.

8. Discussion and Conclusions

The hypotheses were that the framework of dissatisfiers, satisfiers, criticals, and neutrals would make it possible to identify and structure the different factors in the case studies relevant from the perspective of owner-occupants, to visualise gaps between the owner-occupants' perspective and the take professionals have on specific factors, and hopefully also provide insight on how current propositions can be improved.

8.1. Value of Using the Customer Satisfaction Framework

The framework of satisfiers, dissatisfiers, criticals, and neutrals was used in this article to analyse, identify, and structure factors in the response of owner-occupants to concrete propositions in three energy efficiency case studies: #ENEXAP, DTT, and the VvE case. The framework helped to think about the propositions in a new way, because it makes the factors that are important to the owner-occupier visible. The underlying logic of the framework helped to structure the different factors into the categories of dissatisfiers, satisfiers, criticals, and neutrals with their own specific characteristics. The framework helped to structure what should have priority while improving a proposition. The current aim to weed out dissatisfiers is congruent with the insights from the literature. Additionally, it can be concluded that until now, there has been only limited attention for satisfiers, criticals, or neutrals in energy retrofitting. The evaluation, therefore, showed that the framework can help to identify and structure factors relevant for specific retrofit propositions in general.

Additionally, another hypothesis emerged. The framework might also help to clarify the motivations and drawbacks of a specific owner-occupant as to customise a proposition. The categories would in that case be used to analyse the following:

- Dissatisfiers: What problems and fears the owner-occupant has need to be addressed?
- Satisfiers: What is considered of value by the owner-occupant? What are their needs, desires, and expectations?
- Criticals: What are opportunities, drawbacks, and risks, as perceived by the owner-occupant?
- Neutrals: What relevant blind spots of the owner-occupant need addressing?

By generating insights on the different factors, an understanding of the viewpoint of the client is created. This, in turn, allows translating a proposition into an appealing offer and determining how specific factors that are often overlooked by owner-occupants can be addressed. These consist not only of physical factors but also of, e.g., behavioural aspects. Outcomes of two case studies (#ENEXAP and DTT) showed that tips concerning behavioural aspects can leverage the performance of the applied energy measures. The effects were often of an unexpected magnitude for owner-occupants.

8.2. Gaps in the Perspective of Professionals

Professionals are very focused on getting the technical aspects right. They want to make sure owner-occupants understand the relevance of specific factors that are of no interest to the average resident. Additionally, they may not know how to address these matters. In case of required additional ventilation, it seems impossible to first measure if there is a problem, and second, if there is, to convince the owner-occupant to install the equipment. From the #ENEXAP and DTT case studies, it became clear that professionals do not always register what has value to owner-occupants. Factors that cause satisfaction, like beautification, future-proofing, or additional space are not always evident to an executing party. Having a conversation about what is valuable can help to bypass blind spots. There seems to be a tendency among most professionals to focus on the factors relevant in a rather narrow technical perspective only.

Finally, a new hypothesis also emerged here. The framework might be of help when developing or rewriting norms or standards. The quality of norms and standards would improve if experience and knowledge from the user perspective were included in these trajectories. When new technology is being implemented new insights will emerge during implementation and use. If and how the framework could be of help here would however need further research.

8.3. Improving Propositions

The framework helped answer the following question: Can and should the proposition service different factors to extend the appeal of the proposition to a wider audience? Standardisation is on the wish list for both owner-occupants and businesses. For clients, it is perceived as a means to improve quality. Companies are looking for standard solutions as a way to upscale their approach and tap into a market large enough to retrieve a profit. Now the interest in offering standardised retrofit solutions is receiving more and more attention among companies, insights, and experiences, and knowledge from customer satisfaction is becoming increasingly important.

Giese and Cote (2000) noted that customer feedback concerning dissatisfiers is stronger than that concerning satisfiers, especially when it provokes negative feelings about fairness and the accuracy of information provided. Dissatisfiers need to be solved urgently. Complaints from clients can therefore be seen as a valuable source of inspiration for the improvement of the product and/or service. One should realise that only 4% of dissatisfied customers will take the effort to file a complaint (Kolsky, 2015). Therefore, it might be useful to organise a periodical evaluation study. Solving a dissatisfier is relatively easy, as it is usually clear what needs to be addressed. That is not to say the question is easy to answer, as became clear in #ENEXAP. Predicting the final reduction on the energy bill, for example, remains tricky.

Lack of information, the time it takes to get certain information, and/or the way information is structured are factors that keep reappearing in the category of dissatisfiers in different sectors and also emerged in two of the energy efficiency case studies. It is, however, not new to point out that the exchange of information during the customer journey is an important and difficult factor in customer relation management (Dowling, 2002). Through differences in perspective of owner-occupants and professionals, not well-managed customer journeys, the required information is not always at the disposal of the owner-occupant when needed. It is a factor that still needs improvement, while it is not always clear what information is relevant. Information management is a balancing act, and information overload of the owner-occupants should also be prevented.

Service providers need to develop product-market combinations that fit the expectations of owner-occupants on the topic of energy efficiency. Insights derived from an analysis of dissatisfiers, satisfiers, criticals, and neutrals can provide interesting clues to improve propositions. Most people consider global warming to be an important problem (de Kluizenaar et al., 2020). However, this does not imply they will actually invest in energy-efficiency measures. If we look at the satisfiers, one may conclude that the scope of solutions that are of interest to owner-occupants could be broadened, but only if dissatisfiers are dealt with properly. This is compatible with research conclusions from the UK. Wilson et al. (2015) advocate that the "bundling" of efficiency measures into other types of home renovations should be encouraged, rather than stimulating retrofits focused on energy efficiency only. They show that in the UK, energy-efficiency measures are three times more likely to be included as part of broader retrofitting projects that have appeal to the owner-occupant than when considered alone. Only one out of 10 owner-occupants planning a retrofit considers energy-efficiency measures only (Wilson et al., 2013). Hereto specific conditions of domestic life associated with renovation activity, both DIY and contractor-led, should be identified (Wilson et al., 2015). Other research also supports the importance of building aesthetics or home appearance in renovation decisions (Novikova et al., 2011; Whitmarsh et al., 2011). The recent increases in fossil energy prices (Khan, 2021) will most likely stimulate the demand for energy-efficiency measures. With the expected rise in demand, the urgency for appealing market propositions increases.

The question is whether enough energy-efficient retrofits can be sold to owner-occupants while we know that only 13% (van der Werf & van Duist, 2020) of the population feels obliged to contribute with a green lifestyle. Focusing on secondary benefits of energy-efficiency measures, like what is being done with comfort improvement and reduction of the energy bill, could help. But then still the focus remains on energy. In the meantime, a very fragmented and technically oriented supply chain is re-organising itself, allowing the delivery of mass customised energy-efficient retrofit solutions for most dwellings. Additional energy services have been developed, such as financial arrangements, loans, subsidies, energy coaches, and local information desks. The retrofit packages available still require considerable investments from owner-occupants. Will energy prices rise to the extent these investments become appealing? Or should we develop additional strategies? Would it be better to find out what the most appealing renovation propositions are, like Wilson et al. (2015) are suggesting, market those with additional energy-efficiency measures, and, if possible, make sure that these propositions must contribute to energy efficiency? This would mean that energy efficiency becomes one of the neutrals in the customer satisfaction framework of other retrofitting propositions. To assess whether this will be a more efficient strategy, additional research is required into how efficiency measures could be "bundled" into other types of home renovations.

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Conflict of Interests

The authors declare no conflict of interests.

Supplementary Material

Supplementary material for this article is available online in the format provided by the authors (unedited).

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Nelleke Nelis, the owner of Making Space, is a construction engineer who switches between the construction world and the world of the residential consumer. She has many years of experience in informing, involving, and convincing residents (groups) at every moment in the customer journey. With her background in construction and housing technology, she can "translate" information and have insight into the wishes of residents and how these can be connected to an energy-saving plan.

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Article

How a Sustainable Renovation Influenced the Environmental Values of Those Involved

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Abstract
Renovation projects are complex and multi-layered as they often deal with architectural, cultural, and social values, as well as aspects of energy efficiency and finance. This article discusses the impact that engaging in a sustainable retrofit had on the environmental values of those involved. The project was the renovation of an existing log cabin structure located on the Ōtātara heritage site at the Eastern Institute of Technology campus, New Zealand. The aim was to make the existing structure as near-zero energy as possible, so it would act as a demonstration facility for sustainable building and living practices and inspire the local community to adopt pro-environmental practices. The completed project is being used by the Eastern Institute of Technology as home to a nature-based education facility where the cultural and creative connections to land, sustainable use of resources, restoration of ecology, and biodiversity management are communicated. The article explains why people chose to be involved with the various stages of renovating and using a sustainable building and their attitudes towards behaving sustainably. The research approach is explorative, making use of qualitative data analysis methods. The study argues that getting involved in a sustainable building can potentially change the values of people through active, systemic, and successive learning, both in the building and operation phases. The key finding shows that involvement only increased as the project gained momentum as people could see that taking part would produce something tangible.

Keywords
environmental values; New Zealand; renovation; sustainable buildings; zero energy

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. Roadmap

This article describes the effect of making a sustainable building on those involved in both its making and current use. The first part of the article (Sections 2 and 3) briefly describes the project and who was involved with its design. Because the building sits within a tertiary education facility, this gave the opportunity to investigate the values held by those engaging with the project and whether there was a change in these because of the engagement. The second part of this article (Section 4) deals with the investigation into values, and the article ends with a discussion of the results, noting the changes that have happened since the building was completed and how these relate back to both environmental and local cultural values.

2. Background

2.1. Renovation of Existing Buildings

In recent decades, energy efficiency has become a common focus in the building sector, particularly when it comes to the renovation of the existing building stock

(Hamilton & Rapf, 2020; Ministry of Business, Innovation & Employment, 2015). Annually, in both New Zealand and the EU, the existing building stock far exceeds newly constructed buildings (Easton, 2007; European Commission, 2010; Stats NZ, 2020). Hence, renovating the existing building stock towards sustainability is critical (Thuvander et al., 2012). In many cases, this requires developing techniques to maintain, refurbish, and adapt new technologies to fit existing buildings so these meet new requirements. In fact, the bulk of residential buildings in New Zealand pre-date the emergence of modern high-level sustainability standards (Easton, 2007). Renovation processes can be complex and there is the potential to misjudge architectural, cultural, and social values in favour of measures that improve a building's environmental performance. Hence, a systematic approach to making a building sustainable should concern the links between its history and the components, materials, and functions of the building (Brand, 1994, p. 94; Cole & Lafreniere, 1997).

2.2. Zero-Energy Buildings

Annually, buildings use over 40% of the total global pimary energy and so are significant contributors to greenhouse gas emissions, particularly CO_2 (Crawley et al., 2009; International Energy Agency, 2009, p. 2; Seiferlein, 2007). Consequently, the concept of a zero-energy building (ZEB) has developed as a realisable target for building design (Marszal et al., 2011). Essentially, a ZEB is one with reduced energy requirements for building materials, services, and operation, with the objective of meeting all energy requirements "from low-cost, locally available, nonpolluting, renewable sources" (Torcellini et al., 2006, p. 2).

In New Zealand, Jaques (2013, p. 74), from the Building Research Association of New Zealand, pointed to the fact there is no agreed common definition of a ZEB, but stated: "Conceptually, it is a building that can generate enough electricity from renewable sources to balance its energy demand over an average year." He went on to suggest that a net ZEB is one connected to energy infrastructure, so that "the energy taken from and supplied to the grid over the year is balanced. The building uses the grid as a battery" (Jaques, 2013, p. 74). As this research concerns the renovation of an existing building, it seemed appropriate to attempt to achieve net ZEB. This meant the building would be connected to the grid but using renewable resources would annually produce as much energy as taken from the grid.

2.3. Affecting Environmental and Cultural Values

Pro-environmental behaviour consciously seeks to minimise the negative impact of people's actions on the natural and built world (Kollmuss & Agyeman, 2002). This entails initiating shifts in attitudes towards environmental knowledge and sustainable actions. However, there is no simple linear relationship between knowledge, awareness, attitude, and environmental behaviour (Kaiser et al., 1999; Wals et al., 2014). Additionally, social and cultural factors shape the development of an individual's values, which in turn guide the development of a belief system and worldview (Gifford, 2011; Stern et al., 1995). Hence, it is important for those bringing their own value system to building renovation to understand the interactions between cultural traditions, the significance of place (or landscape), and natural biodiversity in terms of identity, ecological knowledge, religion, aesthetics, and social status (Loomis, 2000). According to Stephenson (2008), *place identity* is closely connected with self and group identity through events and moments of history associated with a particular tangible site.

The project in question is located within the heritage site of Ōtātara *pā* (village), a place that contains the history and *mana* (power, influence) of indigenous Māori and their links through genealogy to people and places in New Zealand (Department of Conservation, 2017b; Matthews & Johnston, 2015); this had a major influence on those involved in the project. Unlike the European concept of land ownership, for Māori, the traditional connection to land comes from *kaitiakitanga* (guardianship), a role based on deep kinship between humans and the natural world. With this comes the idea of holding responsibility and caring for the land (Henwood & Henwood, 2011; Royal, 2007), by looking after it in an interconnected way for both the extended family and future generations, thus echoing ideas behind modern sustainability. Accordingly, place and space are often seen as interconnected within *Te Ao* Māori (the Māori world). This meant the log cabin (LC) project had the potential to affect sustainability values through its focus on being a ZEB, which in turn linked to the local cultural values of caring for a site of significance to the local Māori.

2.4. The Log Cabin Project

The design of the LC to meet its ZEB target has been described in detail elsewhere (Bahho & Vale, 2020). Figure 1 shows the building before renovation.

As the building is part of the Eastern Institute of Technology (EIT) campus and the aim was for it to be a teaching tool for EIT students and the community, it was agreed that the renovation design concept would be generated and developed by EIT design students. Consideration was given to writing the project brief criteria so that these would fit with the teaching curriculum. A group of six out of a possible 13 students chose to engage in designing the renovation as part of their bachelor of design studies. The other students opted to work on other projects for various reasons (Bahho & Vale, 2020).

The educational aim was to adopt a reflective teaching method that would enable meaningful learning

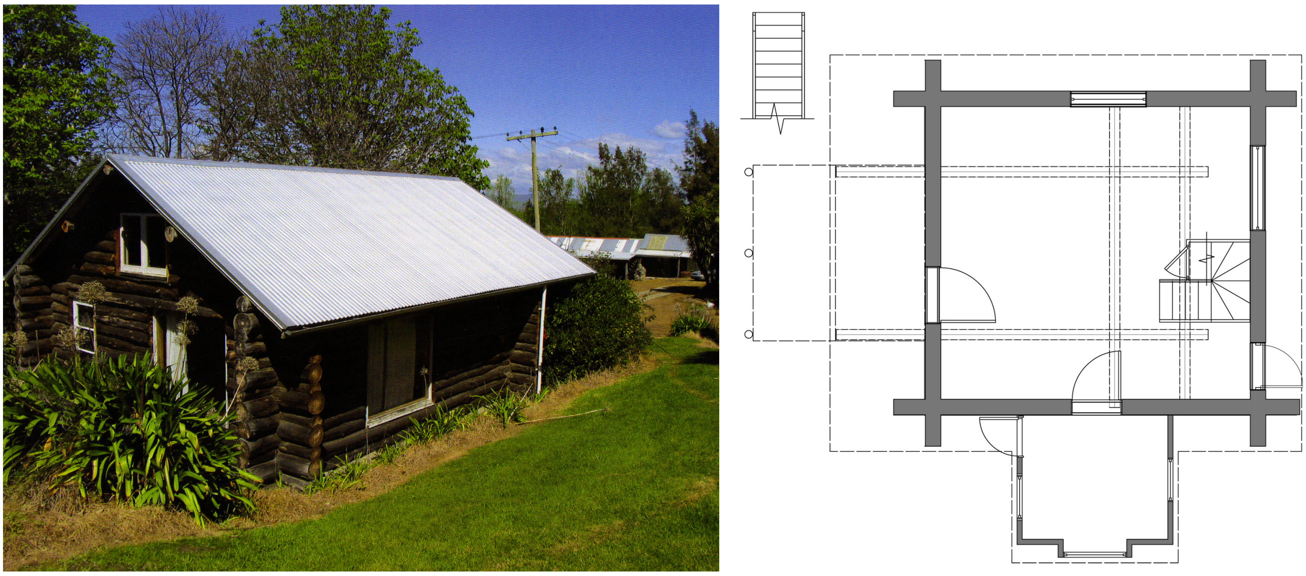

Figure 1. The LC before renovations: A view from the northwest (left) and the ground floor plan (right).

(Schön, 1987; Smith et al., 2009). In addition to discussions focusing on the need for pro-environmental attitudes to manifest the context of sustainability and ecology through design, the students were asked to be mindful of the particular history of the place and site, as well as to fully utilize what existed of the remaining building. The class reflected on the history and characteristics of the Ōtātara *pā*, recognizing its qualities in providing shelter, protection, and clothing for its past inhabitants, as well as being a viable source of food and water. Hence, for Māori, it was considered a sustainable place long before the concept became widely held in the developed world. Figures 2 and 3 show the students' design concepts.

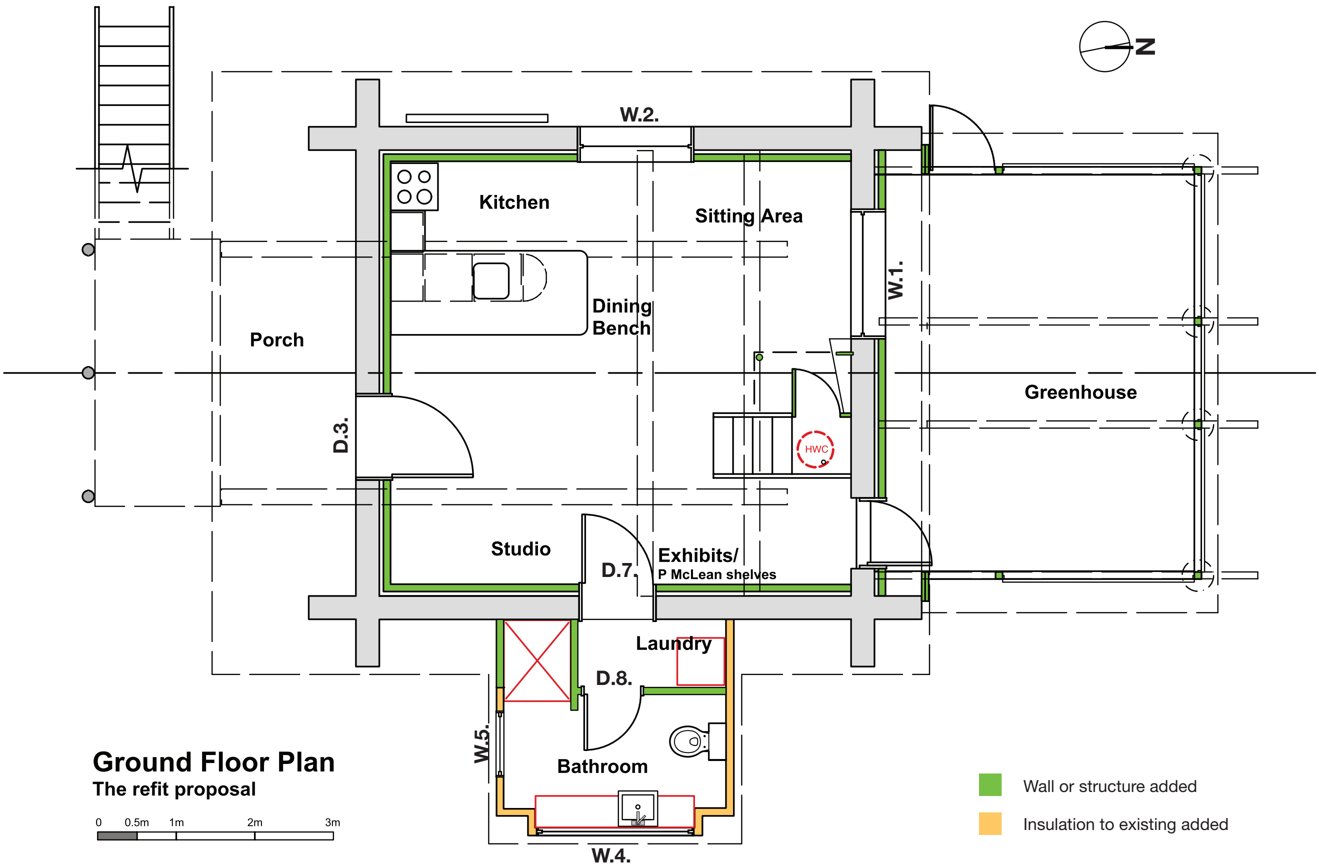

Figure 2. The students' renovation concept: Ground floor plan.

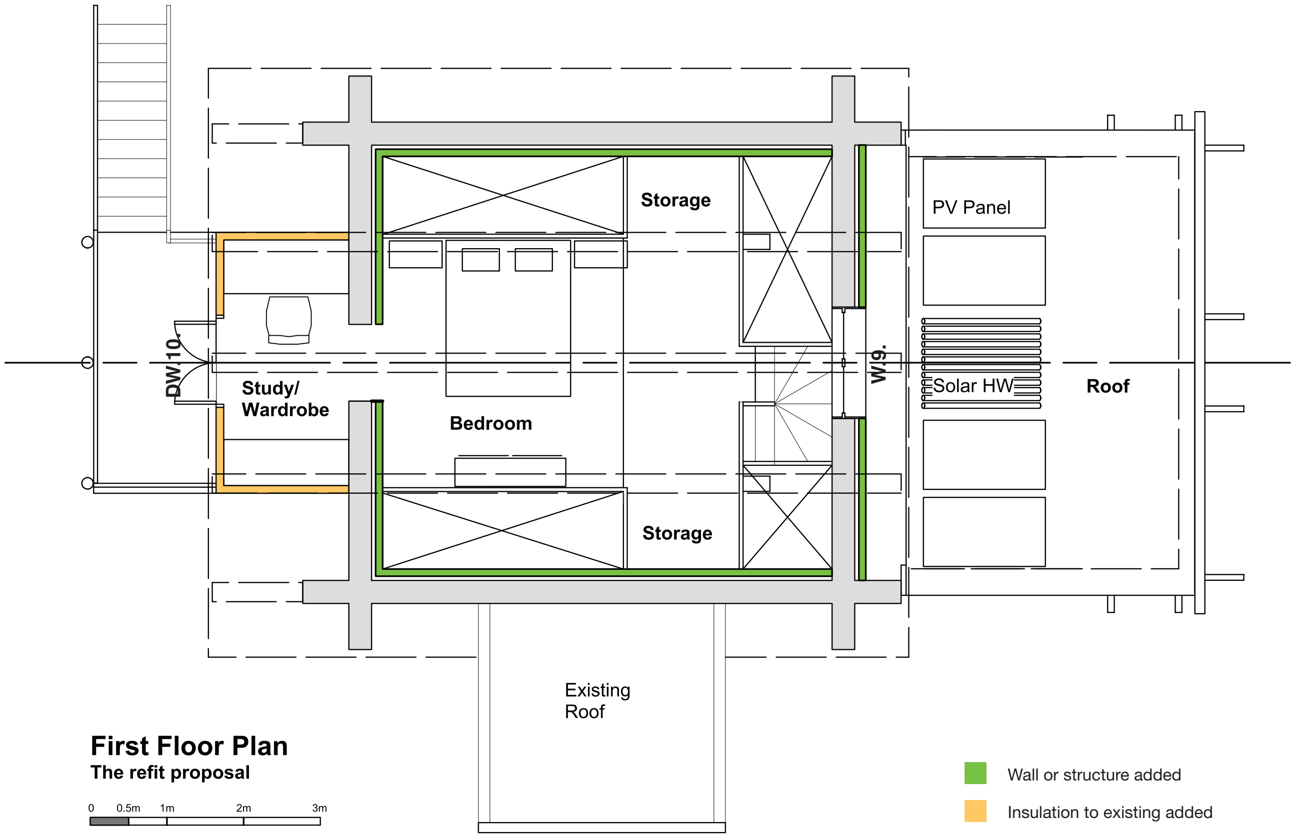

Figure 3. The students' renovation concept: First floor plan.

3. Method and Results

The decision was made to investigate the environmental values of the students involved in the design to see if there was a change after their involvement with the project. The hypothesis was that being involved in making a sustainable building would enhance the environmental values of those involved. This part of the article explains the methods used to investigate the values of those involved, together with the results of the investigation.

Focus group discussions were conducted pre- and post-engagement with the student designers in order to understand why certain individuals decided to take part in the design of the renovation, their attitudes towards behaving sustainably, and how this might affect the level of their future activities. Focus groups were preferred over individual interviews as the students had worked in groups on design tasks and so were used to group discussions and ensuring that each individual had a voice.

3.1. Pre-Engagement Focus Group Analysis

The aim of the first focus group discussion was to establish a benchmark regarding the understandings of and concerns for environmental issues of the six design students before engaging in the project. The focus group session took place in a lecture room at the EIT campus. An hour was set aside for discussion. The first author, Mazin Bahho, was the only non-participant present, and the discussion was recorded. The student participants contributed to the discussion in varying degrees. The focus group used a number of pre-established questions as noted below.

3.1.1. Questions

The discussions explored responses to a two-part question: (a) How concerned are you about the harm that humans are causing to the environment? (b) Looking ahead to the year 2050, are you concerned about the consequences of environmental problems in relation to each of the following clusters: the biosphere, yourself, and other people? The second question was based on Schultz's (2001) three clusters of environmental attitudes related to environmental concerns. These are egoistic (me, my health, my lifestyle, and my future), altruistic (all people, children, my children, and people in New Zealand), and biospheric (plants, marine life, animals, and birds). This type of question has been used before in New Zealand, so, at some point, the results could be compared to other studies (Milfont, 2007, pp. 32–34).

3.1.2. Method of Analysis

Analysis of the data to identify recurrent themes was based on the thematic analysis guidelines (Braun & Clarke, 2006). The recorded data was first transcribed.

Quotes were then extracted and each was referenced to the time the comment was made during the focus group.

After becoming familiarized with the data, an initial list of codes was generated from the various topics brought up by the students. This was done across the data set, rather than for each question individually, in order to identify commonalities running through the data. Working from the perspective of environmental attitudes, the aim was to find out why individuals chose to be involved in the project as part of their education at EIT.

To achieve this, repeated rounds of reading and categorising the data led to the emergence of broad themes, and specific sub-themes within these, all derived from the data (Boyatzis, 1998; Braun & Clarke, 2006). An *initial* thematic map was prepared. The themes identified were the most basic segment or element of the raw data or information that can be assessed in a meaningful way regarding the phenomenon (Boyatzis, 1998, p. 63). These were then reviewed and refined through repeated investigation both of pattern and commonality to create a *developed* thematic map (Braun & Clarke, 2006). Direct quotes from the transcripts were grouped under similar thematic headings to provide a clear illustration of each theme in the participants' own words. From this, a *final* thematic map emerged. While frequency is not necessarily a measure of significance, it offered a sense of the extent to which a particular experience was common across responses, and so the extent to which it might represent a shared understanding or agreement with others.

3.2. Pre-Engagement Results

Consequent to review and refinement, three main themes emerged (Figure 4). These are discussed individually below.

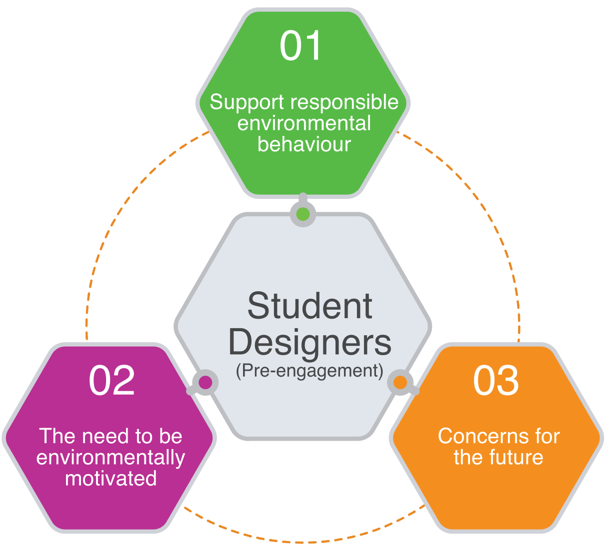

Figure 4. Final thematic map from the student designer pre-engagement focus group themes.

3.1.3.1. Support for Responsible Environmental Behaviour

The students stressed the importance of living sustainably with an emphasis on valuing sustainable living patterns and being in an ecological and organic living environment. They also stressed the importance of preserving the character of the LC, especially in their material choices. There was a notable call for nurturing responsible environmental attitudes in the community through inspiring the behaviour of others, supporting environmental actions, and being passionate about animals and ecosystems. Concerns for environmental behaviour ranged from concerns for self (health and nutrition) to taking a wider view that could still incorporate self (concern for an organic living environment).

3.1.3.2. The Need to Be Environmentally Motivated

The students highlighted the importance of environmental motivation through discussion and practice at the various levels of self, family, and community. They were motivated to maintain elements of the building that have traditional value through preservation, recycling, and reuse. There was also emphasis on the need to acquire in-depth environmental knowledge. They saw involvement with the LC project as an opportunity to focus beyond basic ecological knowledge and issue awareness. Communicating information, including the role of the media, was also stressed.

3.1.3.3. Concerns About the Future as a Result of Human Activities

All participants shared a sense of concern and a degree of pessimism when it came to envisioning the future of the world, due to general concerns about rapid population expansion and increasing demand for materials placing stress on space and resources. Students felt this could result in adverse consequences and environmental problems for the future of the planet and its ecosystems. The importance of preserving natural capital for current and future generations was also emphasised.

3.2.1. Discussion of Pre-Engagement Results

For a qualitative analysis, the group of six participants is small; however, the level and type of information extracted were focused, rich, and diverse. The open-ended questions allowed participants to communicate their own experiences in their own words. As such, the themes identified reflected the spontaneous use of common terms, awareness of the significance of the site, and offered powerful evidence of shared ideas of what it means to be sustainable in New Zealand today. Moreover, observations of commonly experienced reactions to unsustainable practices suggested the participants had strong passion, motivation, and intention to be sustainable, and some wanted to try to influence others to behave sustainably and be ecologically responsible. It also offered an insight into why this group of individuals became involved in the project. Reactions to the two-part question showed the need for in-depth knowledge about sustainable topics and practices so the students could feel confident in taking ownership of environmental issues, and later using this knowledge to empower others into holding sustainable values and having knowledge of environmental action strategies. The analysis offered qualitative evidence for a basic understanding of self, others, and the biosphere in relation to social, environmental, and economic platforms, and that the students had the knowledge and intention to act sustainably.

3.3. Post-Engagement Procedure and Analysis

The plan was for post-engagement focus group discussion with the same students six months after their involvement with the LC project to compare data and look for any effects that might be linked to having been involved in the LC concept design, and whether involvement had any influence on their environmental attitudes or level of future involvement with sustainability. In the event, there were only five focus groups participants. Having moved to another town, the sixth student was not available, although an interview using the same questions was arranged at a later date and the thematic analysis uses data from both the focus group and the interview.

3.3.1. Questions

Both sessions aimed to explore responses to the same questions posed in the first focus group along with this additional question: Did the experience of being involved in the design of the LC project affect the way you acted recently in relation to sustainability?

3.3.2. Analysis Method and Results

Thematic analysis was again used to identify recurrent themes in the data (Braun & Clarke, 2006). The process adopted was similar to that explained above. Upon arriving at a satisfactory thematic map of the data, the dominant themes were organised (Braun & Clarke, 2006; Figure 5). This produced three main themes, which are discussed below.

3.2.2.1. Willingness to Enable Environmental Practices

The students stressed the importance of using energy and other natural resources responsibly and were motivated to an extent to choose sustainable options. They displayed responsible views regarding heritage awareness, and this was also apparent in their concept design. The participants were also keen to acquire in-depth knowledge of the effects of environmentally harmful food growing processing practices (the design incorporated a greenhouse for growing food).

3.2.2.2. Having the Motivation to Support Environmental Actions

Post involvement in the LC project, a number of students tried to convince friends and family to act in an environmentally responsive way, especially regarding building energy choices. The students showed willingness to support others in making environmentally sound decisions and assisting them in changing their environmental behaviour, thus demonstrating ownership and empowerment qualities. As evidence of this, students highlighted the importance of supporting and educating others to act sustainably, being self-motivated in pursuing environmental initiatives, and encouraging others to adopt sustainable practices, in both material choices and operation.

3.2.2.3. Seeking In-Depth and Ongoing Knowledge of Environmental Issues

The students asserted the significance of continuously pursuing knowledge about matters related to ecology and the environment. This included the ability to define the characteristics of a sustainable practice, the ability to recognize the need to extend personal knowledge of environmental issues, and the hope their knowledge could be applied in new and emerging job opportunities related to sustainability. They highlighted the significance of conservationist living patterns, sharing a sense of concern and a degree of pessimism when it came to envisioning the future of the world due to rapid population expansion and increasing demand for materials leading to a diminishing of natural capital, landscape identity, and character of place.

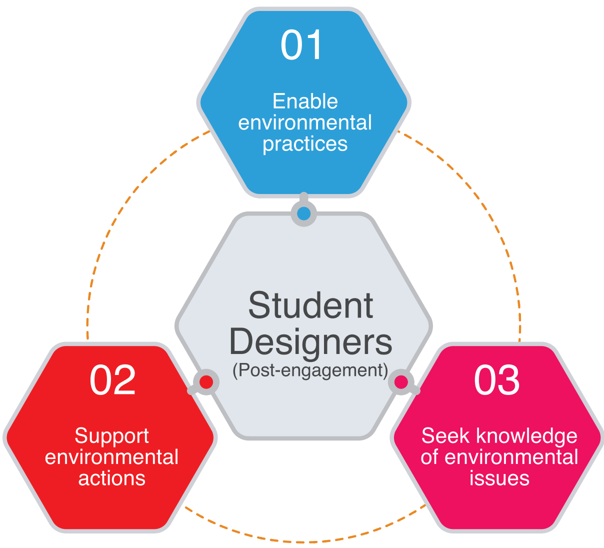

Figure 5. Final thematic map from the student designer pre-engagement focus group themes.

3.3.3. Post-Engagement Discussion

The second interview with the students involved in designing the LC project highlighted the significance of living sustainably, valuing ecological and organic living practices, stressing the importance of using energy and other natural resources responsibly, and being motivated to choose sustainable options in spite of the cost, at least at times. The participants were keen to acquire in-depth knowledge about environmental matters, particularly focusing on the effects of non-environmentally harmful food growing and processing practices. Participants also saw the cultural, historic, and guardianship (*kaitiaki*) dimensions of the Ōtātara site as a significant element of influence on the project's renovation concept and an important reason for taking part in the project.

Subsequent to their involvement in designing the LC, the students' passion for supporting and educating others to act sustainably was observed. They were self-motivated to pursue environmental initiatives and realised the significance of encouraging others to make environmental investments. The discussion revealed a number of instances where they demonstrated active pro-environmental behaviour, such as convincing a close friend to invest in purchasing photovoltaic technology for a lower electricity bill in the face of reduced income and more time at home after retirement. Another student offered to help friends establish a social media network page to exchange information on environmental and health interests, demonstrating ascription of responsibility beliefs (Schultz, 2001).

During the discussion, a number of participants appeared to be inspired by sustainable ways of living, feeling passionate about ecological living practices with a particular focus on ZEBs and water conservation. Planning to build a new home, one participant revealed a responsible environmental attitude by wanting to create a living environment that "will have a sustainable lifestyle like an autonomous place."

Equally important, and as the project work gained momentum, it became more acceptable for people to come forward and become involved. Looking at the numbers, the acceptance threshold or tipping point came when there was enough physical reality emerging from the renovation work and people could see that becoming involved would produce something tangible. Table 1 compares the pre- and post-engagement themes and sub-themes.

4. The Log Cabin Today

4.1. The Ōtātara Outdoor Learning Centre

When the renovation of the LC was completed at the end of 2018, the site became home to the Ōtātara Outdoor Learning Centre, a nature-based education space established on the Ōtātara site at the EIT Campus (Figure 6). This came about as a focus on the future, including sustainability, has recently become a core principle in the New Zealand school curriculum (Department of Conservation, 2017a; Shephard, 2020, pp. 41–58). The Ōtātara Centre is a community education space where cultural and creative connection to the land, sustainable use of resources, and the restoration of ecology and biodiversity management are taught, using the outdoor environment as a context for learning (Passey, 2021). The project is a regional collaboration including the Department of Conservation, local Māori institutions, the Regional Council, Enviroschools, and EIT.

Among the Centre's objectives is the promotion of *nature literacy* across the New Zealand education curriculum, thus encouraging learners to spend more time outside, as well as supporting schools and community groups to use the environment as a context for learning. The LC has become an integrated part of the Centre and further renovations were made to its interior space to open it and make it suitable as an indoor teaching space, thus continuing its heritage of teaching, learning, and outreach dating from the time of the early Ōtātara Arts Centre. In addition, new facilities were added to the Ōtātara site such as an outdoor shelter and an eco-toilet block, as well as a significant improvement to the outdoor space as the whole area has been landscaped with native plants in order to encourage birds and insects.

These new developments saw EIT staff and students reconnect to Ōtātara through the embodied outdoor and landscape experiences that are deeply entangled with that place. Whilst it is clear that these connections differ from person to person, one common connection is passion for the history of the site and respect for those who previously worked on it (Passey, 2021).

4.2. Project Manager Discussion

An interview with the project manager in charge of the operation of the Centre emphasised its impact as a place of natural landscape, distinct building quality, and immersed social history. The importance of developing connections with various regional institutions and community organisations was highlighted within an environment of learning about nature and ecology as well as about culture, society, and heritage. The manager affirmed that the Centre is justifying its purpose of inspiring future behaviour through enabling and promoting environmental education and ecology in different school curricula as well as between disciplines within a sustainability context, hence developing environmental knowledge and capability.

In terms of connecting with nature, the manager stated that the Centre has inspired a number of groups at EIT to become involved in sustainable activities. A number of staff and students developed a plan to regenerate and transform the site (Figure 7), including reviving native species used for Māori traditional crafts (Riley, 2004). The landscape design paid close attention to

Table 1. Comparisons of themes from student designers pre- and post-engagement.

Common Themes	Pre-Engagement Student Designers	Post-Engagement Student Designers
1. Support environmental behaviour and actions	Support for responsible environmental behaviour. Sub-themes: • Living sustainably and promoting it; • Valuing tradition; • Living in an ecologically valuable environment.	Having the motivation to support environmental action. Sub-themes: • Further environmental knowledge; • Encourage and support others to take sustainable actions; • Being motivated to pursue environmental initiatives.
2. Need to be environmentally motivated	The need to be environmentally motivated. Sub-themes: • Motivation through environmental actions; • Role of the media.	Willingness to enable environmental practice. Sub-themes: • The intent to use resources responsibly; • Tendency to opt for sustainable options, sometimes despite the cost; • Seeking knowledge of environmentally harmful practices.
Different Themes	Pre-Engagement Student Designers	Post-Engagement Student Designers
3. Concerns about the future of the planet	Concerns about the future as a result of human activities. Sub-themes: • Sustaining natural capital for future generations; • Stopping promulgation of consumerist attitudes in the media.	
4. Seeking in-depth knowledge of environmental issues		Seeking in-depth and ongoing knowledge of environmental issues. Sub-themes: • Define sustainable knowledge needs; • New and emerging job opportunities; • Knowledge of conserving living patterns.

Figure 6. The LC after the renovation.

Figure 7. A new network of recreational paths at Ōtātara (left) and a group of volunteers planting new areas (right).

preserving limited resources, reducing waste, and preventing air, water, and soil pollution.

The LC now has a role as a learning space integrated with its natural surroundings that provides a venue for teaching and professional development for those wishing to use nature as a context for student learning. The interior space is also utilised for the teaching of both primary and mental health treatment programmes (Figure 8).

5. Conclusions

This article discusses how the LC project was set up and the reflective process of establishing a ZEB as part of a framework for renovating the building to become a demonstration project for sustainable construction and a facility that would inspire responsible environmental behaviour. It describes the involvement of a group of students at EIT and their creation of a brief and design concepts for the building. This provided the opportunity for an investigation into whether this engagement influenced their environmental values.

The research used the process of designing and renovating a sustainable project to investigate the values held by those who did elect to become involved in the process. As might be expected people chose to be involved with the LC project for various reasons. However, pre-engagement studies showed that those who became involved tended to have at least a heightened awareness of sustainability issues and, for some,

Figure 8. Utilising the LC as a teaching space: A primary health teaching session (left) and improving mental health in action (right).

values and attitudes that reflected this interest. The latter included a willingness to adopt sustainable practices, appreciate ecological and organic living methods, and support the responsible use of natural resources. As student designers, the participating group demonstrated high levels of organisation and responsibility in carrying out the requirements of the brief. They were emotionally attached to the project and tackled the work with confidence. The participants were also open to new experiences, reflected in the topics discussed in the studio, and were creative in their design proposals. As a result, the student designers seem to have been affected by their experience of and knowledge gained through the LC project design by being quick in taking steps towards acquiring and adopting environmental values with passion. The students took ownership of the project and worked enthusiastically with developing awareness of sustainable building methods and concern for ecological living practices. Post engagement interviews demonstrated an evolving responsible environmental behaviour in valuing ecological and organic living practices (Kollmuss & Agyeman, 2002), stressing the sensible use of energy and other natural resources, and often opting for sustainable choices despite the cost.

Individually, students also appeared to have developed skills for investigating and evaluating environmental options, particularly living and building energy options, as well as using new media platforms for communication. Consequent to their involvement in the design of the LC concept, student designers demonstrated the intention to take sustainable actions. Armed with environmental knowledge, the students were motivated to pursue ecologically inspired initiatives, both at a personal level and in empowering others to adopt sustainable actions.

Outside the studio, the student group seemed to be motivated to advance and support environmental action in their community. The group was particularly keen on educating others and furthering their environmental knowledge about ecological practices, sustainable living, and healthy diets, and encouraging those around them to make pro-environmental decisions. The student designers were also keen to influence others and the wider community to adopt responsible and sustainable living practices. They considered environmental education paramount in advancing sustainable values, either through schools or via the media, hence demonstrating environmental activism attitudes (Kaiser et al., 1999).

The project's context of converting a near-derelict existing building to being sustainable was also important in inspiring others apart from the student designers to do something tangible and beneficial for both sustainability and the local community. As the project progressed more people were drawn in, initially to help in its construction and since its completion to make both the building and the landscape a place for teaching about sustainability and the environment. It seems that having a sustainable building has inspired the extension of sustainability values into the landscape. This suggests the importance of tangible examples of sustainability in raising interest and awareness of the issues.

The currently operating Ōtātara Outdoor Learning Centre, including the LC, emphasises the multiple layers of social and cultural history that connect with the past together with the ecological and sustainability dimensions that look into the future (Stephenson, 2008). Staff and students who come in contact with it have attached different meanings and levels of importance and engagement with these common entities based on their own individual framing of them. According to the project manager, undertaking learning experiences at Ōtātara has created a sense of meaningful ownership and belonging, as both staff and students transform themselves through guardianship and the physical and emotional care of the place. The renovation of the LC and the development of the Ōtātara Outdoor Learning Centre associated with it are valued by many, however, obviously, those who did not participate in the project could still have the same degree of passion towards sustainability. Additionally, and as an effect of this project, the significance of Ōtātara to EIT and to its employees has increased. Ongoing respect and acknowledgement for this remarkable place are critical because this project on this site has made and continues to make a significant contribution to shaping the attitudes of individuals and the community.

Finally, it is important to note that motivation to engage in a sustainable building project increased after a threshold of engagement was reached. As the project works gained momentum and became psychologically closer (i.e., physically present, with its completion and benefits temporally closer and more certain), it became more acceptable for people to be involved in it. At the early stages of the build, the reality of the renovated building was temporally distant and uncertain resulting in passivity or non-action. The renovation process then made the project visually present, certain, and temporally near to those involved, reducing psychological distance, promoting active action, and increasing voluntary engagement. This shows the importance of all visible actions towards sustainability since these may well inspire others to act.

Conflict of Interests

The authors declare no conflict of interests.

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Article

Unlocking Grey Scientific Data on Resident Behaviour to Increase the Climate Impact of Dutch Sustainable Housing

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Abstract
A "community of knowledge" of representatives of the housing sector in the Netherlands investigated the impact of the behaviour of residents in sustainable housing, both newly constructed and renovated stock. For this, grey scientific data were used, i.e., data and reports from non-university agencies reflecting research commissioned by civil society NGOs and commercial enterprises. The aim was to find perspectives for action (practical "rules of thumb") to increase the impact of sustainable housing on CO_2 reduction and facilitate the implementation of the Dutch national sustainability program. First, a conceptual framework and research model were created to generate the relevant research questions for the sustainable construction sector. An innovative research approach was used where data from academic non-university researchers were enriched by university academic researchers. Experiences with the methodology used are: (a) It implicitly places the many factors that influence sustainable resident behaviour in context; and (b) it makes clear that data from such research can complement university research with useful data from practice, data that are scientifically difficult to use because they are mostly derived from stand-alone case studies. The perspectives for action that were generated are: (a) Sustainable technologies must add new useful functionalities for acceptance; (b) sustainable supply must be tailor-made because households differ and tenants behave differently from homeowners; (c) decision-making about sustainable investments is not only based on financial factors; (d) residents are reluctant to become involved, so it is important that (e) the people representing contractors should be reliable; and (f) people want personalised plans and on-time delivery. Finally, the collected reports turned out to be focused on practice and therefore provided less theoretical information about the rebound effect.

Keywords
CO_2 reduction; community of knowledge; energy transition; resident behaviour; sustainable housing

Issue
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1. Introduction

As the year 2030 draws closer, and 2050 already looms in the distance, it becomes more urgent for all countries to work towards the CO_2 emission reduction targets in the UN Agreements of Paris and Glasgow (United Nations, 2015, 2021). In 2018, the Netherlands started roundtable consultations between government, business, universities, and interest groups of citizens, the so-called "climate tables." These "climate tables" were set up to develop feasible approaches to achieve the goals set in the UN Paris Agreement (Ministry of Infrastructure and Water Management, 2019) and they primarily focused on mitigation and adaptation measures. The climate table on housing and construction took the behaviour of residents into account because its influence on the results could be large, as studies into the rebound effect indicate (de Ridder et al., 2016). However, resident behaviour in relation to climate change is a relatively new area of research. For example, Dutch initiatives such as The Green Village, a field lab for sustainable innovation (https://thegreenvillage.org/en), and the SenseLab (https://www.tudelft.nl/en/architecture-and-the-built-environment/research/research-facilities/senselab), have been set up by TU Delft to gain more insight into this. And there are comparable research projects in other countries. However, given the task at hand, there is an urgent need for insight into the behaviour of residents, in order to develop perspectives for action.

This urgency has been increased because of the lawsuit brought against the Dutch government by the NGO Urgenda. In 2015 and 2018, Urgenda took the initiative to sue the Dutch government for its lack of adequate measures to achieve the goals of the Paris Agreement (De Rechtspraak, 2015, 2018). The lawsuit was followed up by an implementation program in the 2019 Urgenda report (Minnesma, 2019). That the Dutch population realises more and more that action is needed on climate change is illustrated by a survey conducted by the NIDO institute: The authors interviewed 300 randomly selected Dutch people and concluded that the percentage of people concerned about climate change had increased by 15 percentage points in the past three years, up to 63% (Dalen & Henkens, 2019). This was supported by a survey by Statistics Netherlands (CBS, 2021). Another indicator of a change in public attitude towards climate change can be found in the level of "flight shame," which has increased from zero to 13% in the same period (Bos & Rusman, 2019). The growing focus on climate change in the student population is reflected in the nationwide student strikes on February 7 and March 14, 2019, following the appeal of the young climate activist Greta Thunberg in Sweden (Nagtegaal & Peek, 2019).

Despite these signals of a positive change in attitude towards climate change in the Dutch population, the CO_2 emission reduction results of sustainable living appear to be lagging. This can be at least partly attributed to resident behaviour (Oosterhuis et al., 2014). The 2016 report of the Amsterdam Auditor's Office on the results of energy-saving measures in social housing can therefore be seen as a wake-up call regarding this issue in the Netherlands (de Ridder et al., 2016). A survey of 5,000 home renovations in 2011–2014 conducted by the auditors' office concluded that, despite investment in renovations in sustainable energy, energy consumption has hardly decreased; this is due to insufficiently attuned resident behaviour. Despite the annually increasing urgency (Netherlands Environmental Assessment Agency, 2014), renovations for sustainability appear to be focused more on production and less on the influence of resident behaviour on the ultimate mitigation result (Netherlands Environmental Assessment Agency, 2014). Although research into the influence of resident behaviour has increased over the years, the emphasis is mainly on the acceptance of sustainable investments in housing renovation, as shown, for instance, by Ebrahimigharehbaghi (2019), and less attention is given to the situation once housing is occupied.

Driven by the urgency of the situation in the Netherlands and in view of the lack of focus on resident behaviour, a "community of knowledge" on behaviour in sustainable housing was set up. This consisted of representatives of housing associations, municipalities, energy companies, a gas distribution company, a housing developer, a company involved in sustainable community-building, and universities. In 2017, this community of knowledge made an inventory of available research and data, both scientifically and semi-scientifically produced by scientists in non-university research centres (the so-called grey data), about the influence of resident behaviour on the mitigation effect of sustainable housing. It covered both new housing and housing renovations of the existing housing stock. The aim was to make these results available to those working on this topic in the construction and academic sectors. In 2019, the results of this inventory were evaluated with the support of TU Delft (Overtoom & Ortiz, 2019). These are summarised here. The conceptual framework is described in Section 2, the research questions in Section 3, and the data collection and analyses in Section 4. The conclusions can be found in Section 5, with an answer to the research questions in Section 5.1, followed by the evaluation and comments in Section 5.2, and some reflections in Section 6.

2. The Conceptual Framework and Research Model

In the Dutch situation, most of the energy people use at home is electricity for appliances and natural gas for central heating (Druckman & Jackson, 2008; Gill et al., 2010; Santin et al., 2009). Depending on whether the house is newly built or sustainably renovated, residents display a diversity of positive and negative behaviours in sustainable living (Burton, 2012). According to Sanders (2014), residents also copy the behaviour of others, which can reinforce positive and negative behaviour in groups and thus influence residents' decision-making, their sustainable choices, cooperation with neighbours, and their investments. Additionally, Tamis and Staats (2014) have pointed out that visible, positive experiences with sustainable technologies in a neighbourhood can make residents more likely to also invest in this technology.

However, due to a lack of appropriate behaviour in residents, the intended energy savings are not always achieved (Caird et al., 2008; Gatersleben et al., 2002; Gill et al., 2010). Such non-adaptive behaviour also disturbs the opportunities for sustainable action of organisations and enterprises involved, such as municipalities, energy-producing and distributing industries, housing associations, and housing entrepreneurs (Hens et al., 2015; Rooijers et al., 2006). The differences between predicted and actual energy consumption are currently also a concern for municipalities and the national government, as these prevent the agreed targets to be met by 2030 and onwards. The conclusion is that when preparing the renovation aimed at CO_2 reduction, non-adaptive resident behaviour must be taken into account (Ministry of the Interior and Kingdom Relations, 2011).

2.1. The Conceptual Framework

There seem to be two types of resident behaviour both of which are part of the rebound effect. The direct effect occurs when a person refuses to adopt more sustainable behaviour—in this case, for instance, the correct use of the installed technology. The indirect effect occurs when financial savings are redirected to environmentally unfriendly products or behaviours (Nadel, 2012, 2016)—for instance, households investing savings from heating on the purchase of a new car, or using savings incurred from the installation and use of solar panels on more lighting in the house. The occurrence of the rebound effect can be directly traced back to the classical paradox from economic behavioural theory described by Jevons (1865). There is still only little knowledge of the impact of the rebound effect (Dütschke et al., 2013), especially with regard to behaviour linked to housing. The general notion that people base their choices on economic consideration (Fouquet & Pearson, 2012; Thomas & Azevedo, 2013) as well as on social-psychologically driven daily practice (Hofstetter et al., 2006) is less of an influence.

In practice, both types of rebound effects occur simultaneously and are intertwined. As far as scientific research on this theme is available, the rebound effect seems to stand in the way of sustainable results in the Dutch housing sector (Santin, 2012). Therefore, to ensure a shared focus at the start of the community of knowledge mentioned before, a conceptual framework on the rebound effect was discussed and elaborated (see Figure 1). Based on the work of Sanders (2014), the group confirmed that collaboration between residents and professionals can only be productive if both seek and implement a joint approach. This is illustrated in Figure 1 (right).

Explanation of the conceptual framework:

1. The rebound effect (Figure 1, left): When residents in sustainable housing perform a behaviour that counteracts the desired behaviours, due to a lack of abilities (horizontal axis: left-"low" ability, right-"high" ability) and/or motivation (vertical axis: bottom—"low" motivation, top—"high" motivation), this produces the rebound effect (red arrow). The desired behaviour, on the other hand, starts with growing awareness of the lack of sustainability in the present situation, followed by increased participation in sustainable decision-making, resulting also in the encouragement of more sustainable behaviour in others.
2. Behavioural change can only lead to sustainable results if residents and professionals from government, institutes, and companies achieve collaboration. This is illustrated in the diagram on the right, where residents adopt a longer-term orientation (horizontal axis) and expand their focus from the immediate living environment to that of the city and the region (vertical axis). Professionals, on the other hand, also will have to adapt in order to meet the residents halfway (grey-shaded area).

2.2. The Research Model

The research approach of this community of knowledge differs from a more conventional research approach, which would mean opting for new scientific research. Instead, the approach entails the use of grey data as scientifically as possible, i.e., research results from non-university institutions. The research model has been developed by the community of knowledge and is illustrated in Figure 2. In addition to research from universities and related research institutes, there are numerous research results, documents, and reports on energy-saving and sustainable behaviour in sustainably built housing produced by more commercial research institutes. The research is usually carried out on behalf of organisations and companies active in the Dutch

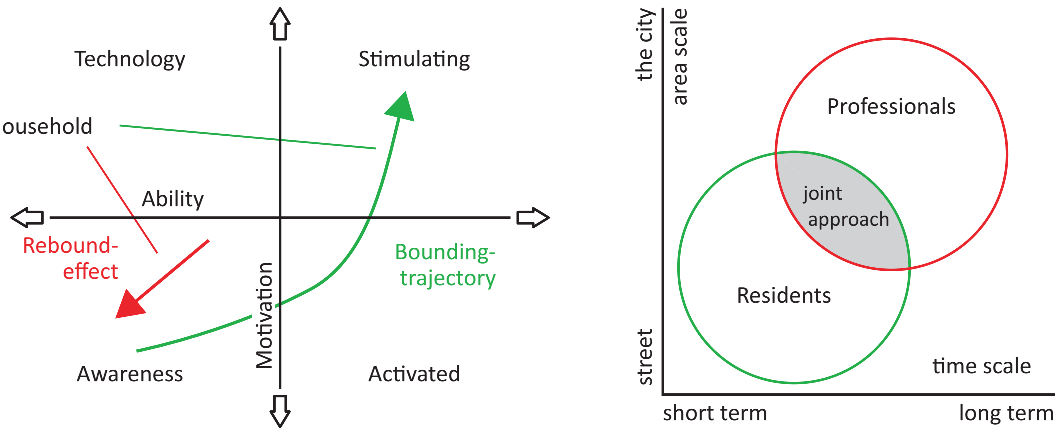

Figure 1. Conceptual framework of the rebound effect (left) based on joint approach (right).

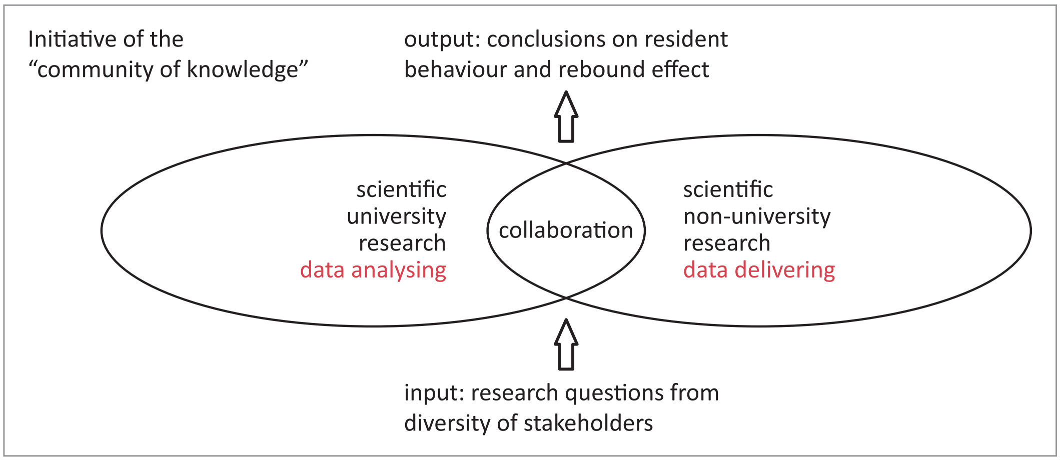

Figure 2. The research model visualising the setting of the research and the relations between the different factors.

housing sector; government institutions, municipalities, semi-commercial institutes, social housing organisations, and commercial enterprises that work on increasing the sustainability of housing in the Netherlands. Most of this research is conducted by consultancies or by academics from non-university research organisations. In practice, this research is not made available to universities but is kept for their own use, for commercial purposes, or because it is simply not considered compatible with university research. The community of knowledge has taken the initiative to make these reports accessible for analysis in a scientifically sound manner. This analysis of already available data can help to gain more insight into the aforementioned perspectives for action to attain more sustainable results in the housing sector in the Netherlands in the short term.

This model shows how scientific non-university data (i.e., the research results from academics at non-university bodies) is analysed by scientific university research, to answer the questions posed by a diversity of stakeholders in the sustainable housing and construction sector in the Netherlands. This approach of mobilising a research community of participants from different disciplines working jointly can be seen as a form of transdisciplinary research (Hadorn, 2008). This research methodology provides adequate new approaches for common problems. The composition of the community is continuously monitored.

3. The Research Question(s)

Considering the approach of the study as explained in Section 2, which aims at generating practical perspectives for action, the community of knowledge elaborated the central research question as follows: How can grey data, i.e., non-university scientific research, be used to generate relevant knowledge about the behaviour of residents in sustainably built housing to improve mitigation results and thus facilitate and accelerate the national energy transition? And which perspectives for action does this provide for the Dutch housing and construction sector?

In order to develop the intended practical perspectives for action, the group has elaborated a number of sub-questions. To this end, two workshops were organised. Companies and universities involved with housing and construction—the main actors—were invited to participate. The first result was an inventory of already known perspectives for action, which were clustered thematically in an axis field diagram developed during the workshops (see Figure 3). These thematic clusters were then discussed to identify the remaining questions, which led to nine sub-questions.

The relevant sub-questions which were developed in the two workshops follow from the discussed perspectives for action. These are:

1. Which environmental/situational factors influence sustainable behaviour?
2. Will installation companies continue to sell old-fashioned installations?
3. How to prevent obstructive behaviour by residents (consciously and unconsciously)?
4. Do residents know how to use new installations?
5. Do residents want to use new installations?
6. On which scale do households participate in government sustainability campaigns?
7. Do residents accept sustainable government policy?
8. Under which conditions do households invest in sustainable technologies for their homes?
9. On which scale will households and their neighbours invest in sustainable technologies?

All these questions are related to the main three themes that together influence the decision-making of households of resident behaviour, sustainable technology innovation, and government involvement.

4. Data Gathering and Analysis

Research reports (Sections 2 and 3) were collected by community of knowledge participants by approaching colleagues within their own organisation and asking

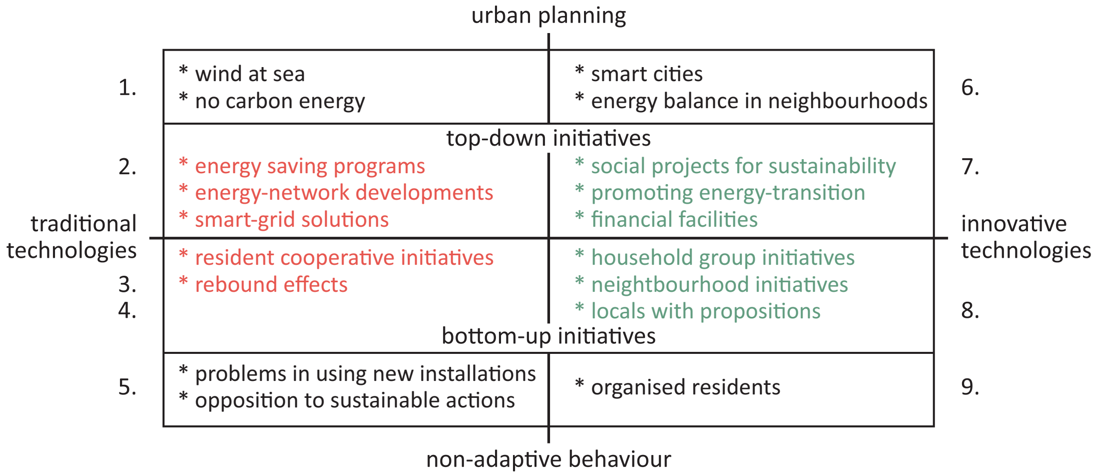

Figure 3. Diagram for "sustainable resident behaviour," with clustered action-perspectives and sub-questions numbers. Notes: The (exemplary) behaviour of residents of sustainable housing was placed in a diagram with opposites by the participants: bottom-up and top-down initiatives (vertical), and traditional and innovative technologies (horizontal). To supply the scale of the individual and the city in the vertical axis, "urban planning" is featured at the top of the diagram and "non-adaptive behaviour" at the bottom. The diagram shows positive (in green) and negative (in red) examples of sustainable resident behaviour.

other befriended organisations to do the same. In total, about 100 documents were received. These were fed into a database for the study and the results were discussed in the community regarding diversity and quality. Once the stream of documents petered out, the active collection was ended and a check was done on whether enough and sufficiently diverse documents had been received for the first analysis.

4.1. Review of Documents: Core Group

Before the assessment, all documents were scanned for duplicates and content relevance (Dutch context, sustainability, and housing were the main criteria for relevance). Leaflets and brochures were left out of consideration, so that research reports remained, which all turned out to be from the period 2011–2018. The resulting documents ranged from user segmentation images, internal company presentations, and research reports from commercial research firms to government or municipal policy documents, including new research proposals. This selection process ultimately resulted in 40 documents of sufficient quality and relevance for the intended analysis and for answering the sub-questions and the central research question.

For a proper identification of these 40 documents, they were examined in the following categories: (a) the source organisation, (b) whether the government was involved, (c) method of publication, (d) the methods of the research, and (e) the focus of the research (residents, policymakers, housing associations, etc.). The results are presented in Table 1.

Table 1. Summary of documents reviewed in detail.

Creators	Research office 18	Educational institution 13	Municipality 6	Company 8	Housing association 3	Governmental 5	Total 53
Issued By	Government 10	Other 3					13
Document Type	Planning document 5	Review 4	Research paper 13	Case study 7	Presentation 2	Other 7	38
Research Type	Quantitative 11	Qualitative 9	Mixed-methods 7	Other 10			37
Aimed At	Residents 4	Government 9	Housing associations 2	Marketing companies 3	Other 3		17

Note: Some documents fit in more than one column.

The next step in the document review was to identify the predominant topics covered in these documents regarding aspects of sustainable living behaviour (see Table 2). Using this pre-selection as a guideline, three themes appeared to be leading in the 40 selected documents: (a) the type of motivation used to exhibit environmentally friendly behaviour (comfort, energy, social, and financial), (b) the behavioural differences between people in relation to sustainable results, and (c) research into methods that are used to motivate people to adopt sustainable behaviour.

The actual researchers and authors of these documents were either employed at a consultancy or worked for an internal research department of an energy company or a housing association and did their work in collaboration with universities. There are 11 documents for which the research appears to have been conducted by a government agency.

It is notable that these documents are especially interesting because "real-life" situations have been investigated. Most documents lacked a theoretical framework and adequate control of the results. The quality of these documents is different from that of scientific research.

Most of the selected 40 documents mention behaviour as an important factor in reducing energy consumption, which confirms the importance that science has attached to behaviour in reducing energy consumption over the past 20 years (Jackson, 2005). In most documents, however, behaviour is treated very generally, without specific references to particular technologies or investments. Describing behaviour and categorising it also turned out to be a common theme in these reports. The motivations most often cited for acting sustainably turned out to be saving energy and money and improving the comfort of living indoors.

5. Conclusions

5.1. The Research Questions Answered

The questions formulated by the participants of the community of knowledge (Section 3)—based on the conceptual framework and research model as summarised in the diagram of clustered perspectives for action (Figures 1, 2, and 3)—are shown to be mostly oriented on either technology or behaviour. Therefore, the answers to these questions are elaborated following these orientations. They are accompanied by the aforementioned scientific literature which endorses the conclusions. The nine formulated sub-questions are brought together in two new sub-questions (Sections 5.1.1 and 5.1.2).

5.1.1. Technology-Oriented: Answering Research Questions 2, 4, 5, 8, and 9

One of the two reformulated questions is: How do people interact with specific technologies? Or, in a slightly different formulation: How can people be motivated to use and interact with sustainable technologies? This is important for housing construction to be effective in the transition to sustainability.

The first, more detailed conclusion based on the 40 selected reports is as follows: In order to be accepted and thus successful, sustainable technologies must add new useful functionalities. The technology must be given a so-called "comfort factor" for the user, as is also apparent from the result of a marketing expert meeting (Zoetbrood & Gotz, 2015), adapting personal preferences in the performance of a product (Aune, 2001; Chatterton, 2011). One of the reports, a study of 6,000 Dutch households, shows that previous positive experiences motivate households to take more sustainable next steps (van Lidth et al., 2014). Research among 514 households in the city of Utrecht showed that higher-educated people make such steps more easily (de Kleijn & van Leerdam, 2011). An investigation into the entry-level arguments for purchasing a hybrid heat pump shows that the instructions for new technology must be tailored to the user, supplied with sufficient information, simple, understandable, and up-to-date (Engberts & Overdiep, 2016). This means that financial arguments are not always decisive for purchasing new technologies (Zoetbrood & Gotz, 2015). This is confirmed by research among the households of 12 neighbourhoods in Den Bosch, which showed that cheap loans for sustainable investments hardly influence decisions to make these investments (Fudura, 2014). Although a survey among 2,500 respondents confirms that "comfort" properties of sustainable products stimulate their purchase, other examples quoted point to financial advantages, improvement of comfort, and a positive contribution to the environment. Exemplary behaviour of others also appears to stimulate such purchasing behaviour (van der Werf et al., 2015; van Welzen & van Delft, 2014; Vringer et al., 2014). Where households and individuals differ, customisation is desirable to encourage people to make sustainable investments and to choose relevant new technologies. For example, children within a household can have a decisive influence (de Wilde, 2018; van Lidth et al., 2014; van Middelkoop, 2014).

In conclusion, sustainable technologies must fit into people's lives so that they will benefit them and will align with their personal motivational goals. For sustainable

Table 2. Summary of topics of documents reviewed in detail.

Motivation Type					Differences	Energy Reduction Method		
General	Comfort	Energy	Social	Financial		Behaviour	Technology	Personal action
8	10	11	4	14	15	22	13	12

technology development, this means that there must be room for different approaches, depending on technology, housing type, and household type.

5.1.2. Behaviour-Oriented: Answering Research Questions 1, 3, 6, and 7

The other reformulated question is: How can the behaviour of residents be positively influenced to reduce energy consumption so that they will participate in and support local initiatives towards sustainability? Second, what is the effect of campaign interventions?

Sustainable behaviour appears to have an influence, but the case studies found in the 40 selected reports indicate that this is not easy. A pilot among 250 households in the cities of Zwolle and Breda, for example, showed that residents are open to the provision of new information, as long as this information is diversified according to the needs of different groups of people and households (NL Agency, 2013). Projects in which residential blocks were renovated one by one show that tenants want predictable planning and homeowners want personalised plans (Netherlands Environmental Assessment Agency, 2014). Positive feedback from others, like neighbours and acquaintances, also appears to stimulate making sustainable choices (Aune, 2001) as well as contribute to positive community formation (Fischer, 2008). It is also apparent from interviews held among households and experts across the Netherlands that there is an interest in a "sustainable customer journey" (a roadmap to becoming more sustainable) with trust as the most important factor, regarding the information as well as the representatives of contractors, landlords, and the government (de Wilde & Spaargaren, 2017). Research conducted in 12 neighbourhoods in the city of Den Bosch shows that good results can be achieved in neighbourhoods for which sustainable supply is still completely new (Fudura, 2014). Polled interventions tend to stimulate sustainable action, according to research in a diversity of Dutch neighbourhoods (Straver et al., 2017). One difference that crops up repeatedly is between tenants (usually of social housing) and homeowners, with homeowners more likely to invest in sustainable technologies. Tenants are more cautious and expect their landlord to do the investments (van Lidth et al., 2014; van Middelkoop, 2014; Vringer et al., 2014).

Unfortunately, no practical examples of the rebound effect were found in the 40 selected documents, whereas the documents specifically mentioning the rebound effect were papers published in academic journals (Aydin et al., 2013, 2015; Boulanger et al., 2013).

5.1.3. Perspectives for Sustainable Action

The most promising perspectives for action are: (a) Sustainable technologies must add new useful functionalities for acceptance, and (b) must be user-friendly and customised to the needs of different households, with specific attention to the differences between tenants and homeowners; therefore, (c) financial arguments must be used less predominantly in campaigns. It also appears that (d) residents are sensitive to the quality of information provided and that (e) the representatives of contractors, landlords, and the government must appear reliable, (f) people want personalised plans and delivery on time, and (g) there is power in repetition: People are more sensitive to the sustainable message when it comes from several different senders, and will make sustainable choices if they trust and know those people.

5.2. The Methodology Reflected

The research of the community of knowledge (Sections 1 and 2) aimed at a double objective: (a) to stimulate the provision of perspectives for direct action, and (b) to evaluate the research design in which data from practice (grey data) was used, with a scientific approach to the analysis of these grey data. The ultimate aim was to contribute to the acceleration of creating sustainable housing in the Netherlands, taking into account the need for building one million new homes in the Netherlands in the coming years, in addition to the necessary sustainable renovation of approximately 3.5 million homes (Ministry of Infrastructure and Water Management, 2019).

5.2.1. The Research Methodology

The central question about the research methodology used is: What does this methodology add to traditional academic research methodologies? This question should be addressed both in the data collected and the results of the analysis. With regard to the collected data, it can be noted that the useful data from the scientific approach turned out to be mostly from location-based case studies which were elaborated by academics or advisors to municipalities and housing associations. The useful reports were few in number and many of them were not prepared in a sufficiently sound scientific way, which made it difficult to substantiate the conclusions. Therefore, only 40 documents made it to the selection.

On the other hand, these reports provided very pure information directly related to the source and based on research among households in neighbourhoods and districts. They were mostly small-scale stand-alone case studies. Second, the focus of most reports and underlying research was on practical sustainable action and less on the effectiveness of government incentives. In principle, these reports offered a fresh perspective and pointed toward new results and insights. The actual outcome, however, is that the research results of this new approach largely confirm what is known from scientific research. The second aim of the study has thus not been achieved. The mutual confirmation of the different research methods, on the other hand, can also be seen as valuable and a basis for repeating the research on a larger scale.

6. Reflections

6.1. Interactive Database

During the evaluation session held in 2019, it was suggested that if this research approach were to continue, a new and interactive database should be developed together with the participating bodies. This would encourage more active participation, as well as sharing and discussion of the results with the participants during the data collection, potentially resulting in a wider variety and higher quality of the reports provided. This would also increase the chance of new perspectives for action.

6.2. Exchange of Knowledge

The documents that the participants submitted were not only from their own companies and organisations but also documents originating from governments and universities in the collection. This indicates that there is a one-way use of scientific research for research from practice on behalf of companies and organisations that work in the field of the sustainable housing construction sector (see Figure 4, left).

When the community of knowledge came together to reflect on results, participants put forward the impression that the aforementioned "research from practice" carried out by non-university research centres is considered less relevant by the universities, and thus little or not included in university research. Actual two-way traffic in the exchange of information is preferable, with universities including results of more practically-orientated research in their own studies. Construction companies require scientific reflection on their day-to-day practice, so they can optimise their contribution to sustainable housing (for illustration of this approach, see Figure 4, right).

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Conflict of Interests

The authors declare no conflict of interests.

Supplementary Material

Supplementary material for this article is available online in the format provided by the authors (unedited).

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Figure 4. Visualisation of sustainable housing data exchange: Current (left) and proposed (right).

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Article

Reusing Timber Formwork in Building Construction: Testing, Redesign, and Socio-Economic Reflection

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Abstract
In 2018, the construction sector was responsible for 39% of the worldwide energy and process-related carbon dioxide emissions (Global Alliance for Buildings and Construction et al., 2019). This is partly due to the embodied carbon, which represents the carbon emissions related to building construction and material production (LETI, 2020). While zero energy buildings and zero energy renovations start to get the operational carbon down, the circular economy aims to do this by closing material loops and stimulating the reuse of discarded materials in building construction (Ellen McArthur Foundation et al., 2015). Although it is not a new phenomenon, material reuse does require a substantially different approach and is at this point not yet common in the building industry. This is especially true for load-bearing components. This article presents a pilot project for the reuse of discarded timber formwork for the construction of the façade and (load-bearing) substructure of a new house. Through this pilot case and by reflecting on a series of similar cases, it studies the remaining challenges for material reuse but also proposes and assesses redesign strategies that will allow upscaling the reuse of timber formwork. The project shows that although waste, material, and money can be saved by using reclaimed materials, it does complicate the design and construction process and, as such, does not necessarily reduce the total project budget. Moreover, for reuse to become a current practice, new design approaches and collaborations will need to be established. Finally, socio-economic factors must be considered to increase the acceptance of reclaimed materials in new building construction.

Keywords
circular economy; circular housing; CO_2 reduction; material reuse; resource efficiency; sustainable architecture

Issue
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1. Introduction

Considering the current climate and sustainability crisis, a lot of focus is put on reducing building-related carbon emissions. This is not surprising, since the building sector is responsible for almost 40% of worldwide energy and process-related CO_2 emissions (Global Alliance for Buildings and Construction et al., 2019). While policy makers and the construction sector are moving increasingly towards the construction of zero energy buildings, another aspect of sustainable construction is slowly reaching the foreground: the embodied carbon. This is the carbon that is emitted during the construction, maintenance, and end-of-life processing of a building and its materials (LETI, 2020). The embodied carbon of buildings has been underrepresented in the sustainability discourse in favour of the more acute need to lower operational carbon. Some studies even suggest that the embodied carbon of buildings is increasing due to higher material consumption in low and zero energy buildings

(Giordano et al., 2017). Others show that embodied carbon is much more related to the types of buildings and the materials that were used (Hoxha et al., 2017). Overall, however, with decreasing operational carbon, the embodied carbon is starting to represent the larger share of the total carbon emissions of buildings (LETI, 2020). Without efficient strategies for reducing it, the construction sector will never be able to effectively and adequately reduce its environmental impact. Reducing the impact of material use in construction cannot be considered separately from the recent developments regarding the circular economy (Ellen McArthur Foundation et al., 2015). Much of this material impact is related to the extraction of virgin resources and the waste management of discarded materials after all. Circular construction aims at closing material loops by reusing or recycling construction materials or by growing the required resources in a biological cycle (Galle et al., 2019). Effective reuse of building materials requires strategies for the repurposing of discarded materials on one hand while transitioning towards a more futureproof construction practice that extends the functional life of new buildings and materials on the other. The latter, which is generally called design for change, aims at facilitating reuse and repurposing of buildings and building elements in the future (Brancart et al., 2017). The former allows an immediate reduction of both waste production and virgin material use, and can, as such, lower embodied carbon instantly (Brütting et al., 2020). This article focuses on direct reuse.

While not yet common practice, material reuse is not a new phenomenon. Many interesting examples have been scattered throughout history, especially at times when material costs where high and labour was much less expensive (Addis, 2012; Fivet & Brütting, 2020). Within the context of the circular economy, the reclamation of building materials during demolition, so-called urban mining, is gradually finding its way into practice (Arora et al., 2020; Koutamanis et al., 2018). Reclaimed bricks, interior doors, and roof and floor tiles start making up a second-hand market, as they are often being sold by demolition companies (Devlieger et al., 2019). Exemplary cases do however show that the use of reclaimed materials requires specific attention and current design approaches often fail to accommodate them (Kawa, 2021). In many cases, the exchange of materials between a demolition site and a construction project will require careful planning. The main challenges for reuse appear to be situated on a social and organisational level (Gorgolewski, 2008). Moreover, unknowns about the material properties often require additional studies or testing (Brütting et al., 2019). As a result, reclaimed materials are often applied in building layers with low-performance criteria where quality assurance is not required or can be more easily done.

This article zooms in on the use of reclaimed timber. It argues that the reuse of building materials and in this case, timber can help substantially lower the embodied carbon levels of buildings. Yet, to increase the uptake of reclaimed building components, some barriers need to be overcome. Therefore, the article first aims to provide a general overview of reuse strategies and current limitations, based on a review of built cases. Secondly, it goes in-depth on one specific challenge: the reuse of discarded timber formwork. The functional lifetime of timber formwork is short compared to its technical life. This currently leads to high amounts of waste and loss of economic value. This article, therefore, studies the reuse potential of formwork in housing construction and investigates redesign strategies to increase it, based on an A-to-Z case study for a new circular house on IJburg Amsterdam, compared to several similar projects. The research focuses on the following two specific questions: What is the load-bearing capacity of the formwork elements? Which connection types will allow more effective reuse?

Specific about the central case study is that one of the building owners is also the project architect and principal investigator of this study. As such, he was actively and positively involved in the material reuse. The other residents, his family, and another family with which they share the house, were less involved. While they acknowledged the value of a circular design and construction approach, they were also concerned about the impact on the building layout and appearance. This kind of resistance is not uncommon. Aside from technological challenges, there are also socio-economic barriers to overcome (Charef et al., 2021). Consumers are used to choosing from extensive catalogues of buildings materials. Moreover, they lack experience with and knowledge about circular products, their advantages and drawbacks. This results in a lack of confidence about the durability, quality, and usability of the products, along with a general resistance to change. Many of the studied cases report such resistance in one or more of the project stakeholders. Yet, open communication but especially the quality of the design and finished project managed to persuade them. In most projects though, the focus remains on the technological solutions, as this type of sustainable construction is still in a more explorative and experimental stage (Schut et al., 2016). While this article does primarily consider the technological barriers to material reuse, it does reflect on the socio-economic aspects that will be required to scale-up circular construction practices.

2. Building With Waste: Reclaimed Timber for Façades and Load-Bearing Construction

To better understand and position the pilot project that is presented in the following sections, this article first drafts a more general framework by reflecting on a series of representative cases. These cases focus on the application of reclaimed timber products in façades and load-bearing structures. Figure 1 shows the nine selected cases. Although they all share similarities as well as

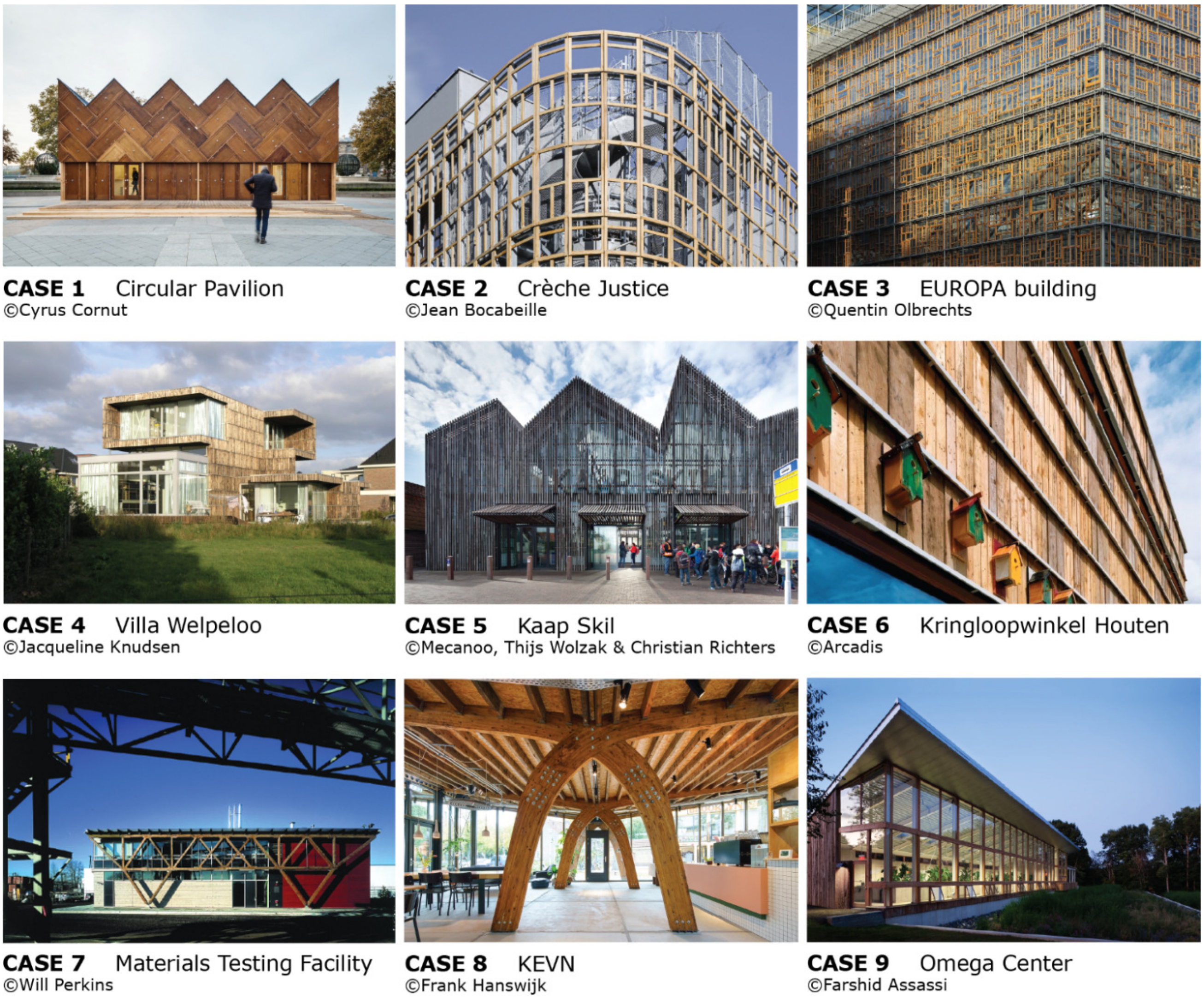


Figure 1. The nine selected project cases.

feature some unique characteristics, they can be roughly divided into three groups. Cases 1 to 3 represent the reuse of reclaimed building products like doors and window frames in new façades. The EUROPA building is the only of these cases in which the reclaimed elements—in this case, window frames—were reapplied for the same function. Cases 4 to 6 all include façades that were clad with reclaimed materials from outside the building industry: from damaged cable reels over hardwood sheet piling to used transport pallets. Cases 7 to 9 finally represent the category of buildings in which reclaimed timber is used as part of the load-bearing structure. Such cases are of particular interest in the scope of the presented pilot project. They are however far less common and underreported in (scientific) literature.

Table 1 summarises the most relevant project information and lessons learned. These were gathered from existing literature (including scientific articles, new articles, and interviews with designers or building owners). While each project is characterised by a distinct approach, it is possible to draw some general conclusions. Based on the variety of cases, it is reasonable to assume that these conclusions can be generalised, though it is also clear that many of the studied aspects should be considered case by case. The analysis focuses on four aspects: motivation, process, application, and cost.

In most cases, sustainability aspects like waste savings and a reduction of the embodied energy provided the main motivation for the application of reclaimed timber. The choice for material reuse was generally part of much broader sustainability ambitions related to energy performance, circularity and, in the case of the Omega Centre, even regenerative design. Yet, in all cases, the designers or building owners point towards the improvement of the project's overall architectural quality as one of the main advantages of material reuse. The reclaimed materials were made highly visible and often have a prominent position in the project, even in cases like KEVN and the Materials Testing Facility, where they are part of the load-bearing structure. In some projects, the origin of the materials plays a role in the design concept. This is especially clear in the case of Kaap Skil, where maritime sheet piling was used in the façade of a maritime museum, but also in the EUROPA building, with its façade consisting of reclaimed window frames from all EU member states.

The prominent position of the reclaimed timber in the architectural concept warrants an equally prominent position in the design and construction process. The limited availability and often small volumes of reclaimed materials, logistic considerations regarding transportation and stocking, and the many unknowns related to material properties and quality assurance require specific actions. These differ fundamentally from the conventional approach, in which new building products are often selected at a later stage or the end of the process. In many of the presented cases, the design team, therefore, collaborated with reuse experts. Two lessons

Table 1. An overview of the basic project info and most important lessons learned.

Case	Reuse	Lessons Learned	References
Circular Pavilion Paris (FR), 2015 Encore Heureux Architects	Interior doors as façade cladding	The final design had to be adapted to the exact sizes of the door panels	Valenzuela (2015) and Kawa (2021)
Crèche Justice Paris (FR), 2020 BFV architects with Bellastock	Interior door (frames) as façade cladding	Material changed for final design based on unsuitable performance	Myers (2020) and Kawa (2021)
EUROPA building Brussels (BE), 2017 Samyn & Partners	Window frames from different EU countries	A double façade guarantees adequate energy performance, a mathematical system defines the seemingly random pattern of the differently sized frames	Wright (2017)
Villa Welpeloo Enschede (NL), 2009 Superuse Studios	Timber from cable reels as façade cladding	The design of the façade is based on the size limitations of the reclaimed timber pieces	Superuse Studios (2009) and Kawa (2021)
Kaap Skil Texel (NL), 2011 Mecanoo architecten with Pieters Bouwtechniek	Hardwood sheet piling as façade cladding	Use of maritime wood enforced architectural concept for maritime museum, contractor attracted based on involvement in demolition project	Opalis (n.d.) and Mecanoo (n.d.)
Kringloopwinkel Houten Houten (NL), 2012 Arcadis	Transport pallet wood as façade cladding	Reuse of pallet wood resulted in considerable savings, the design and outlook of the façade are defined by a large variety of timber pieces	DGBC (2020)
Materials Testing Facility Vancouver (CA), 1999 Busby + Associates Architects with Fast & Epp Partners	Timber trusses, glulam beams as floor decking	Underestimation of glulam's strength, reclaimed timber a lot cheaper, strong involvement of partners, scepticism of users turned to appreciation of result	Public Architecture (2011) and Brütting et al. (2019)
KEVN Eindhoven (NL), 2020 Superuse Studios	Timber frames	The frames were cut to make purlins from the same timber, the entire pavilion can be disassembled for another reuse	Superuse Studios (2020)
Omega Center New York (USA), 2009 BNIM Architects with Planet Reuse	90% of total timber use, including frames, panels, doors, beams	Specifications should be flexible to allow changing material choices based on availability, the involvement of a reuse broker helps maintain a tighter schedule, reclaimed timber is considerably cheaper than new FSC timber	Public Architecture (2011)

were drawn from almost every project: It is important to prepare for material reuse early in the design process and the design and construction team need to be sufficiently flexible to deal with and adapt to the many unknowns. Additionally, it appears that strong collaborations, as well as open communication, were key in making the reuse work.

The selected cases all feature reclaimed timber in façade and load-bearing applications. In most cases, the materials were applied for functions different from their initial use. Even more so, several of the reclaimed materials originally weren't building products at all. In almost all cases the materials first had to be processed to be sized, protected, and installed properly for their new function. Thanks to its great workability, this is relatively simple when using timber. While reclaimed materials are getting more and more common for the cladding of façades, it is more difficult to find cases of reclaimed load-bearing structures. This is most likely due to the required performance levels and associated risks. These structural requirements often ask for creative solutions. The timber trusses in the Materials Testing Facility for example were recomposed from the most qualitative pieces of the reclaimed truss elements. Due to unknowns about the structural integrity of the glulam beams, the design and engineering team decided to apply them as floor decking, thus overdimensioning the structure but also avoiding having to rely on the strength of the glue (Public Architecture, 2011).

A final important aspect is the cost. It is difficult to provide a general conclusion or even make a meaningful comparison between the cases for this. After all, the available budgets for the different projects differed largely as well as the origin of the reclaimed materials and the technical complexity related to their reuse. While the thrift shop in Houten was realised with a small budget (one million euros for 1392 m^2), shipping window frames from all over Europe has undoubtedly only increased the total project cost of the EUROPA building. In general, savings can be made with respect to the actual material cost. In most cases, these materials would have been discarded as waste after all. Yet, the logistics and additional work hours often increase considerably. In many cases, an additional partner had to be added to the team or contractors and engineers needed to be involved earlier and more intensively. Moreover, temporary storage, transportation, and, in some cases, prototyping and testing, ramp up the budget. As such, it is not possible to say that material reuse will automatically result in a reduction of the project cost.

In most of these cases, the end user was not heavily involved in the building design and material selection. Out of the nine projects, only Villa Welpeloo (case 4) was realised on behalf of the actual end user. The residents and building owners, a young couple, had the express wish to build a sustainable home by integrating as many aspects of circular design as possible. They commissioned a young architectural firm and together they achieved 60% reuse of existing materials. This required making some concessions, but these were acceptable seen as the circular design was one of the initial requirements. The other cases mainly concern public buildings and, as such, the end user was not intensively involved in the construction process and circular design choices. Moreover, cases like the EUROPA building, using a mix of different reclaimed window frames, or Kaap Skil, using maritime wood in a maritime museum, show that reclaimed materials are still mostly used in "eye-catching" applications. As such, they underline the potential added value of circular design. This does however avoid owners or end users having to make concessions in terms of expected interior appearance or supposed quality of materials that often hinder the application of reclaimed materials.

The reference projects show that qualitive material reuse can be achieved, but the exceptionality of the buildings also shows that it remains a niche and the use of reclaimed building materials has not yet become commonplace in more everyday construction. While the availability of used materials appears to be increasing, their reuse is not yet established, partly because the recycling of materials such as aluminium, glass, and concrete granulates has already been perfected (Rijksdienst voor Ondernemend Nederland, 2021; Sanders & van Timmeren, 2018). Although the costs of circular material and product use outweigh those of other materials in the long term, it appears that the initial additional cost is insufficiently quality-enhancing to convince customers, home or building owners. This has a negative impact on the uptake of used materials, for example in the construction sector in the Netherlands (Oostra, 2020).

3. The IJburg Villa of Reused Wood as Central Case Study

This article focuses on a central case study, a residential villa in Amsterdam, the Netherlands. The project was realised in 2017 and is a pilot project for the application of reclaimed timber formwork in new building construction. This case is of particular interest as it reuses the timber formwork for load-bearing elements. Thanks to mechanical testing, performed by the authors, the case provides insight into the capacity of the formwork and its reuse potential for different building elements. The presented method can be adapted to study the reuse potential of other load-bearing building products. In this case, the discarded plywood formwork was applied both in the outer walls and the floor, as part of the (load-bearing) structure. Figure 2 shows design drawings of the building, pictures of the building during construction, and pictures of after its realisation. As large quantities of plywood formwork are discarded regularly, there is a clear potential for its reuse, even on a larger scale. The goal of this pilot project was to study the feasibility of formwork reuse, especially for structural applications.

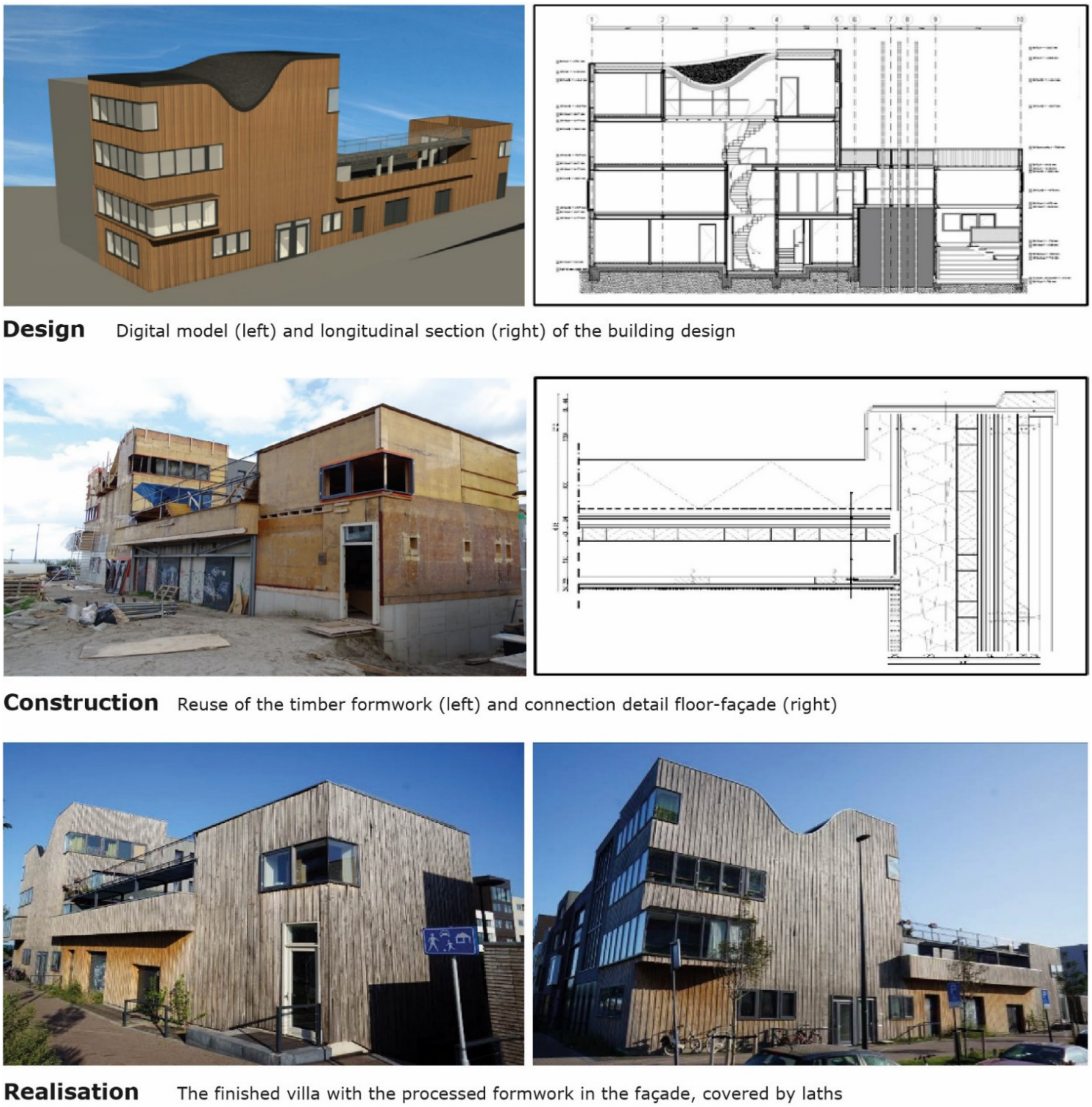


Figure 2. Design, construction, and realisation of the villa with reused wood.

The irregularities in the formwork make it less suited for visible finishing layers. Their high thickness of up to 17 centimetres, however, makes them well suited for load-bearing walls or floors.

At the construction site, the panels were put together to form a four-layer shell of walls and floors. The façades at the end have a load-bearing function. Between these façades, the floors are supported by steel trusses. A steel beam is required at various locations to bridge the dimensional differences of the plates. The wooden floors disappear under insulation material and a cast floor. On the outside, the house is finished with vertical wooden laths. Little of the wooden formwork elements is visible in the final stage. By the time the house was finished, no traces were left of the origin of the reclaimed materials.

4. The Timber Formwork

The purpose of this project is to investigate the reuse and recycling potential of old formwork elements. The CO_2 emission and energy consumption will be 522 kg CO_2 for every cubic meter of plywood based on research by Ashby (2013), Hill et al. (2018), and Danielson (2014). The CO_2 emission factors of the materials are based on processing, manufacturing, energy conception, and transportation. The reuse of this material will result in a considerable reduction of the carbon footprint. This article looks at different opportunities based on the reuse of old formwork of a Dutch concrete contractor specialized in concrete production. A lot of timber formwork is produced every day, but its reuse is limited. The maximum amount of use cycles (as formwork) is determined by the flatness of the shelf and the project characteristics and could rise to a maximum of seven times. Therefore, it is good to look at new opportunities for old formwork that cannot be used anymore. The formwork elements are designed without making any structural calculations. The goal is to make formwork elements with a completely flat and smooth surface in a cost-efficient way. When they are discarded, the elements are taken apart and stored until they are pulverized (see Figure 3).

4.1. Composition of the Formwork Elements

As shown in Figure 3, the formwork elements consist of pine beams that are connected perpendicularly to other, load-bearing pine beams using timber screws. The beams are covered with plywood and lacquered to keep the timber dry. A PVAC glue connects the plywood to the beams. The shelf is fixed with additional staples. Due to the irreversible connection of all these layers, the formwork cannot be disassembled after being discarded.

4.2. Types of Formwork Elements

There are two types of formwork elements (see Figure 4):

1. The A-series consists of formwork elements with full cross sections on large scale.
2. The B-series consists of formwork elements on sample scale. Within this B-series, two types are provided: (a) the BB-series, consisting of a full cross-section sample, and (b) a BZ-series consisting of just the shelf, without a connected beam.

Figure 5 presents the characteristics of series A, B, and BZ.

5. The Mechanical Properties of Timber Formwork

As no structural analysis or mechanical testing is performed during the development of the timber formwork, information about the mechanical behaviour is lacking. For the application of the formwork in the construction of the villa, it was, therefore, important to perform a series of mechanical tests and evaluate the derived properties. This section presents the results of this testing, performed by the authors. Based on this, it reflects on the role and importance of testing procedures and barriers to overcome.

5.1. Bending Test

The samples of the A-series were tested with a 3- and 4-point bending test. The 3-point bending test is carried out to determine the maximum concentrated load. The samples are positioned on two supports with a span of 1800 mm. An equally distributed line load is increased

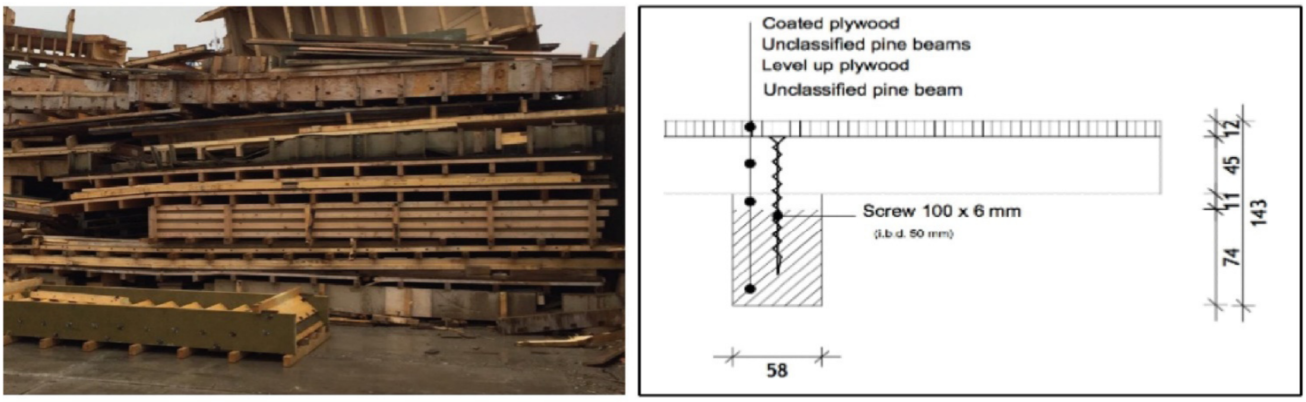
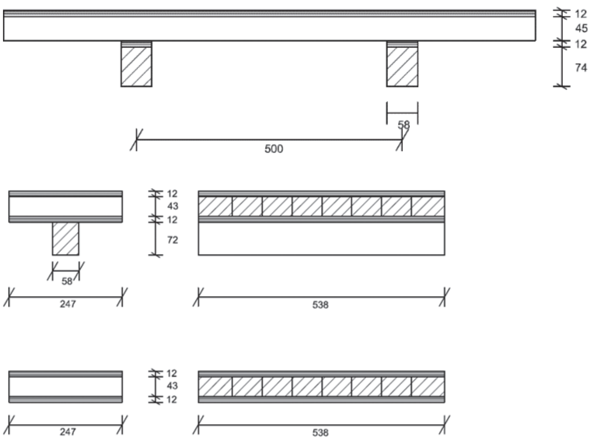


Figure 3. The basis material of old formwork at the depot (left) and its construction (right).

Figure 4. The two types of formwork elements: A-series (left) consists of formwork elements with full cross sections, B-series (right) consists of formwork elements on sample scale.



Property	Average	Average deviation
Length	1899 mm	0 mm
Width	998 mm	6.82 mm
Total height	153 mm	0 mm
Shelf height	60 mm	0 mm
Area of holes	926 mm2	718 mm2
No. of filled holes	18	14.4

Property	Average	Average deviation
Length	538 mm	0 mm
Width	248 mm	2.53 mm
Moisture content beam	15%	2.11%
Moisture content shelf	18%	3.40%
Mass	6.3 kg	0.18 kg

Property	Average	Average deviation
Length	538 mm	0 mm
Width	246 mm	2.83 mm
Moisture content shelf	23.0%	2.95%
Mass	5.2 kg	0.04 kg

Figure 5. The test samples represent different types of formwork, varying in shape and size. From top to bottom: The A-series consists of nine samples, each derived from one big shelf; the B-series consists of seven samples, each derived from one big shelf; final the BZ-series consists of six samples, each derived from one big shelf.

with 4 kN per minute. The results are expressed by force-deformation graphs (Figures 6 and 7). All samples show a significantly higher strength than required for residential floors.

Further on, the needed force for a deformation of 7,2 mm is in the range between the minimum and maximum calculated estimated force values of 2,28 kN < F < 25,7 kN. Therefore, it can be concluded that the load-bearing part does not only consist of the lower beam, but the elements are also not fully connected.

The 4-point bending test was carried out (see Figure 7), in addition to the 3-point bending test, on the samples of the A-series. A 3-point bending test indicates the maximum concentrated load of the sample. The place of failure will take place close to the middle of the span, where the maximum bending moment occurs. A 4-point bending test, however, is preferred because failure in this case occurs at the weakest spot. The cause of this is that in the area between the loads, the bending moment remains constant and the shear force is equal to zero. The load capacity of the formwork elements is compared to the requirement according to the Dutch Building Act, which states a minimum concentrated residential floor capacity of 3 kN. The allowed deformation equals L/250 = 7,2 mm. The samples in this experiment are not loaded to failure like in the 3-point bending test. This test stopped when the deformation was a bit over 7,2 mm because strength characteristics were already

Sample	Ultimate load (kN)
A1D	25.4[1]
A3D	24.5
A4D	25.6
A6D	27.3
Average	**25.8**
Deviation	**1.0**

Sample	Needed force for maximum deformation (kN)
A1D	10.3[2]
A3D	11.6
A4D	11.6
A6D	12.3
Average	**11.8**
Deviation	**0.3**

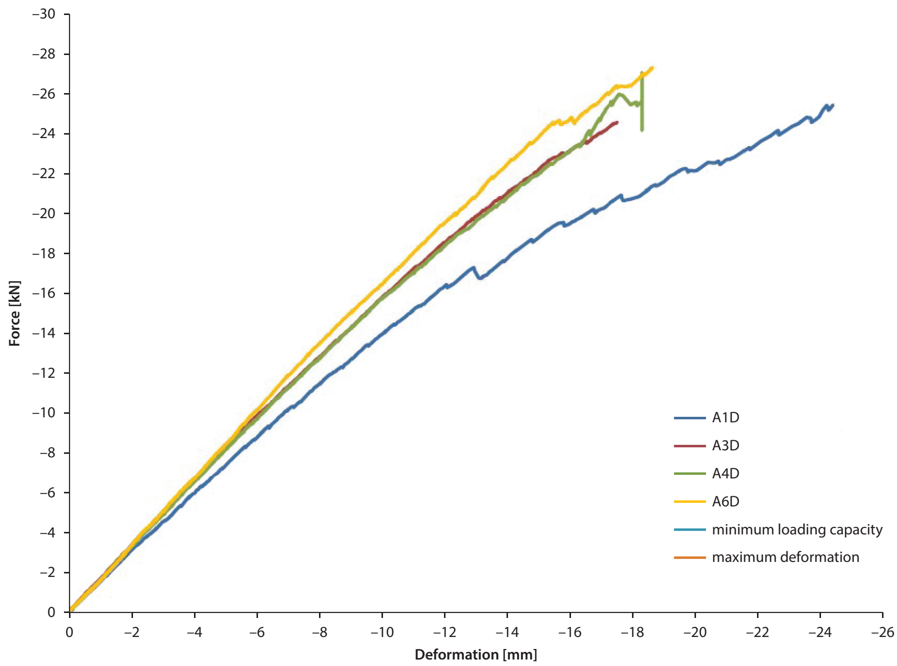


Figure 6. Ultimate load (left), deformation (centre), and required force for maximum deformation (right) based on a 3-point bending test.

Sample	Needed force for maximum deformation (kN)
A2D	18.7
A7D	17.0
A8D	17.5
A9D*	13.7[3]
Average	**17.7**
Deviation	**0,6**

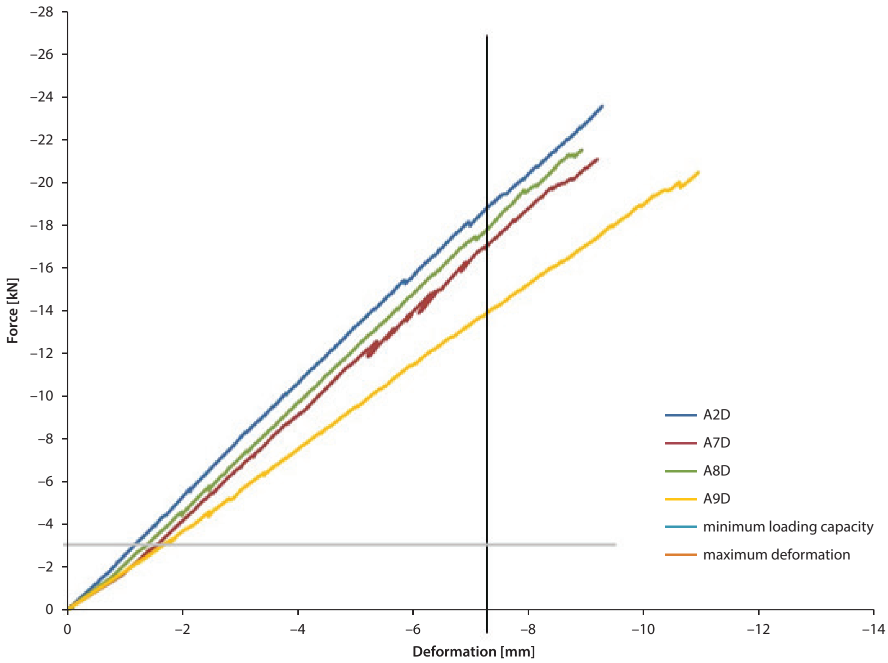


Figure 7. Deformation (left) and force for maximum deformation (right) based on a 4-point bending test of A-series samples.

known. The graphs reaffirm that all elements meet the requirements for structural use.

Using the moduli of elasticity of the beam and the shelf (determined in Sections 5.2 and 5.3, respectively), the maximum span can be calculated. The uniformly distributed load for a residential floor equals 2,5 kN/m^2. The maximum deflection of a residential floor is L/250, according to the Dutch building code NEN-EN 1995–1-1. Using this information, the maximum span can be calculated as 3,07 m.

5.2. E-Modulus of Spruce

The formwork consists of different parts like beams of unclassified spruce and plywood. To measure the e-modulus of the different parts several tests have been performed. For the spruce, an axial compression test was done. To make an indication of the compressive stress, the strength is assumed to be around the strength of the lowest class: C14. With this assumed strength, the expected load can be calculated, to have a good indication of the result:

$$F = \sigma \times A = 14 \times 45 \times 74 = 47 \text{ kN}$$

Based on the section of the spruce (C14) it is assumed that the applied force will be 47 kN and the modulus of elasticity will be 7000 N/mm^2. The three samples of the C-series have been loaded in compression. First, the samples had to be prepared for the dimensions to be following the Eurocode. Therefore, the samples were sawn to 45 × 74 × 270 mm. These samples were loaded axially parallel to the grain, so the direction of the grain in the samples is equal to the longitudinal axis (270 mm).

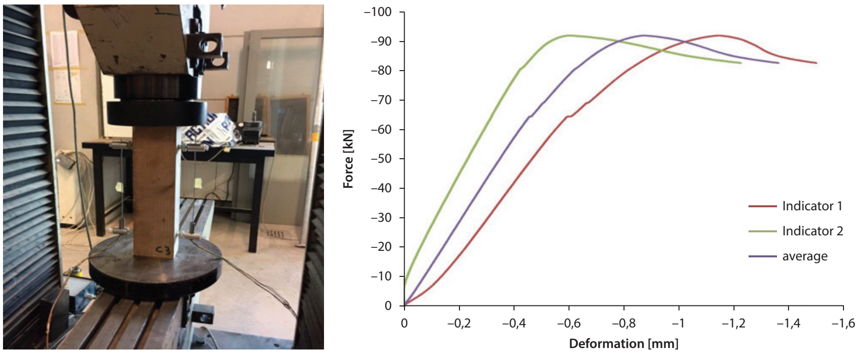
The deformation, due to axial loading, is measured by two LVDTs. Therefore, it is possible to determine if buckling occurs. The deformation is measured over a length of 2L/3 which equals 180 mm. The fixed points of the deformation indicators are placed L/6 = 45 from the top and 45 mm from the bottom, and these positions are determined following the Eurocode. This test is executed with a bench press, which is controlled by deformation, so the deformation is constantly increased over time. The speed of the deformation is equal to 0,5 mm/min. Figure 8 shows the results of the test. Based on these experiments the e-modulus of the spruce is calculated with Hooke's law.

Based on the linear parts in the graphic, the average modulus of elasticity is 7425 N/mm2. This is a plausible answer because the modulus of elasticity of spruce is 7000 N/mm^2 on average.

5.3. E-Modulus of the Shelf

The modulus of elasticity of the shelf is derived through a 4-point bending test with a span of 480 mm. The test is executed with a bench press with a 2,0 mm/min deformation. The results of the four experiments are represented in Figure 9.

In general, this study uses a more statistical approach to determine the load-bearing capacity of the formwork. Such a study provides insight into the overall performance of the formwork, which was entirely lacking. The advantage, in this case, is that large quantities of formwork with similar load-bearing capacity become available for reuse every day. Moreover, since the functional life of the components is short, ageing of the material will be limited. Defects are similar and can therefore be generalised in combination with visual inspection. This is not the case for other types of reuse. Urban mining often leads to small batches of materials that have been



Sample	Ultimate load (kN)	Strength (N/mm²)
C1	91.8	27.6
C2	75.6	22.7
C3	90.9	27.3

Sample	E [N/mm²]
C1	7760.2
C2	5809.3
C3	8704.5
Average	**7424.7**

Figure 8. Results of the compression test of the spruce samples.

loaded under different conditions for long periods of time. This requires a more individual assessment (including damage detection of all individual components) and as such remains an important barrier to the reuse of load-bearing components. It is a subject for further research.

6. Reuse Potential and Component Redesign

Based on the case study research on timber reuse and the analysis of the mechanical behaviour of the formwork samples, this section discusses the reuse potential of timber formwork for new construction and studies different redesign strategies that improve the potential for selective dismantling.

6.1. Reuse Potential

The formwork elements have high strength and stiffness. This could be useful for structural applications like floor systems, façades, roofs, and structural walls. In these cases, the timber would be covered and would not be visible in the finished project.

6.1.1. Structural Residential/Utility Floors

The first possible application of the formwork elements is using them as structural floor elements. The minimum loading capacity, according to the Dutch building regulations, should be 1,75 kN/m^2 for residential use and 2,5 kN/m^2 to 5,0 kN/m^2 for utility use. Based on the testing results, the formwork elements are capable of resisting these live loads.

6.1.2. Façades and Roofs

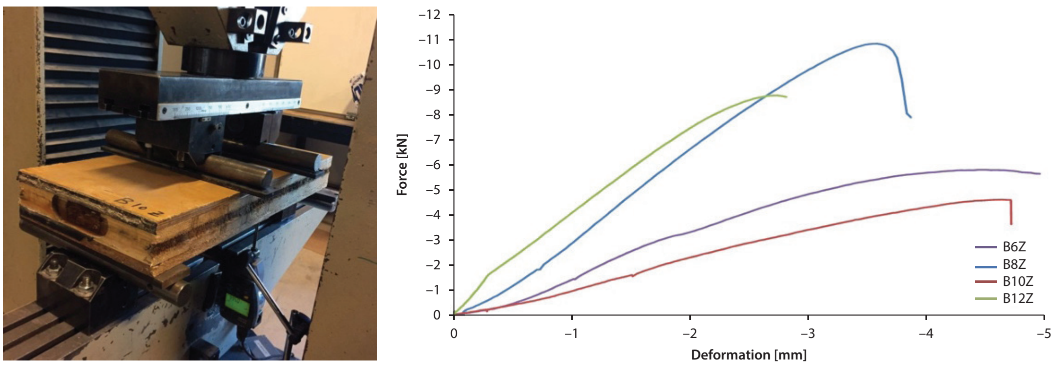
Another application for the formwork elements is using them as façade elements or roof elements. Façade elements will be used as finishing panels and will not support the main structure. When using the elements as load-bearing façades or roofs, it is important to take live loads like snow and wind into account. These forces could be as large as 2,12 kN/m^2, depending on the height and location of the structure.

6.1.3. (Structural) Inner Walls

Formwork elements could be useful as structural inner walls because they have a high strength and stiffness capacity. The space in-between the load-bearing beams, underneath the shelf, could be used for sound and heat insulation. By adding these insulation panels, the elements will meet the requirements of the Dutch building regulations.

6.2. Component Redesign

Now, the formwork elements have a lot of different connectors, which are making the adaptability complex.



Sample	E [N/mm²]
B6Z	578.0
B8Z	1211.2
B10Z	402.2
B12Z	1135.2

Figure 9. Force-deformation graphs resulting from the 4-point bending test of the shelf samples.

The formwork elements can be reused within the production process of the concrete contractor by changing the conventional connections into demountable connections. Nine alternative connections are discussed to find better solutions with low cost, longer lifetime and adaptability:

1. Glue
2. Timber dowels
3. Fixation
4. L-connection
5. Z-connection
6. Bottom magnets
7. Top magnets
8. Vacuum connections
9. Hoisting frame

6.2.1. Material Costs

Figure 10 and Table 2 compare the material cost of the nine options by listing all required materials and estimating their cost. All values are given for one element of 0,5 by 1,8m and are later expressed per m^2. These total costs are again split up into total connection costs and total fixed costs. Since the total fixed costs are the same for all options, it is easier to compare the total connection costs. The analysis considers the cost per time unit, considering the difference in lifespan between the shelf and beam elements. The total lifetime of the beam is assumed to be seven uses.

6.2.2. Factors of Cost and Revenues

The costs of the options for reuse are also partly determined by production costs because certain acts require more man-hours than others. The production costs of these specific methods are based on assumptions. The conventional method has a time factor of 1. Other methods are compared with the conventional method. Table 2 shows the labour costs.

Figure 11 estimates the total lifetime cost by combining the material and investment cost and incorporating the ease of use and workability for reuse. Ease of use refers to the expected workability of the connection option. Workable for reuse means that the element can be adapted and reused for different purposes. This includes how easy it is to saw the element. A waste factor estimates the amount of formwork that would still be discarded. In Figure 11, the cost is represented as a ratio of the cost of the conventional elements. The best option is the one with a low value for the material, time and waste factor, and a high value for the ease of use and the workability for reuse. Therefore, only values below one are accepted (green) for the material, time, and waste factor and only values above one for the ease of use and workability for reuse.

				0. Conventional	1. Glueing	2. Timber dowel	3. Connection by fixation	4. L-connection	5. Z-connection	6. Magnet connection (bottom)	7. Magnet connection (top)	8. Vacuum connection	9. Hoisting frame
			Beam length	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	8	8
			Dimensions [m2]	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	4	4
Element	**Price**	**Unit**	**Info**										
Plywood including beams	€ 5.98	/m2	Thickness 12 mm	€ 5.38	€ 5.38	€ 5.38	€ 5.38	€ 5.38	€ 5.38	€ 5.38	5.38	€ 23.92	€ 23.92
Pine timber beams	€ 0.30	/m	74 x 58 m2	€ 0.54	€ 0.54	€ 0.54	€ 0.54	€ 0.54	€ 0.54	€ 0.54	0.54	€ —	€ —
Screws	€ 0.04	/pc	Length 100 mm	€ 1.44	€ —	€ —	€ —	€ —	€ —	€ —	—	€ —	€ —
PVAc glue	€ 2.16	/L	Witte houtlijm	€ 0.16	€ 0.16	€ 0.20	€ 0.16	€ 0.16	€ 0.16	€ 0.16	0.16	€ 0.64	€ 0.64
Screws	€ 0.02	/pc	Length 20 mm	€ —	€ —	€ —	€ —	€ 0.72	€ 0.54	€ 0.09	—	€ —	€ —
L profile	€ 0.70	/m	Aluminium	€ —	€ —	€ —	€ —	€ 2.52	€ 2.52	€ —	—	€ —	€ —
Z profile	€ 0.70	/m	Aluminium	€ —	€ —	€ —	€ —	€ —	€ 2.52	€ —	—	€ —	€ —
Dissolvable glue	€ 86.40	/L	—	€ —	€ 3.00	€ —	€ —	€ —	€ —	€ —	—	€ —	€ —
Magnet	€ 3.37	/pc	25 kg	€ —	€ —	€ —	€ —	€ —	€ —	€ —	6.74	€ —	€ —
Magnet	€ 1.11	/pc	6 kg	€ —	€ —	€ —	€ —	€ —	€ —	€ 2.22	—	€ —	€ —
Timber dowel	€ 0.01	/pc	40 mm	€ —	€ —	€ 0.09	€ —	€ —	€ —	€ —	—	€ —	€ —
Steel strip	€ 1.43	/m	For magnet	€ —	€ —	€ —	€ —	€ —	€ —	€ 2.58	—	€ —	€ —
Vacuum system	€ 80,000.00	/pc	6 systems	€ —	€ —	€ —	€ —	€ —	€ —	€ —	—	€ 480,000.00	€ —
Hoisting system	€ 475.00	/pc	6 systems * 3 pcs	€ —	€ —	€ —	€ —	€ —	€ —	€ —	—	€ —	€ 8,550.00
Hollow tube section	€ 3.83	/m	25x25x2 mm, 2pcs	€ —	€ —	€ —	€ —	€ —	€ —	€ —	7.66	€ —	€ —
Total cost		**/m2**		**€ 8.36**	**€ 10.09**	**€ 6.90**	**€ 6.76**	**€ 10.36**	**€ 12.96**	**€ 12.19**	**€ 22.76**	**€ 120,006.14**	**€ 2,143.64**
Total connection cost		**/m2**		**€ 1.62**	**€ 3.33**	**€ 0.14**	**€ —**	**€ 3.60**	**€ 6.20**	**€ 5.43**	**€ 16.00**	**€ 120,000.00**	**€ 2,137.50**
Total fixed cost		**/m2**		**€ 6.76**	**€ 6.76**	**€ 6.76**	**€ 6.76**	**€ 6.76**	**€ 6.76**	**€ 6.76**	**€ 6.76**	**€ 6.14**	**€ 6.14**
Life span shelf	—			7	7	7	7	7	7	7	7	7	7
Life span beam	—			7	7	7	7	350	490	490	490	28800	21600
ratio	—	—		1	1	1	1	50	70	70	70	4114.285714	3085.714286
Connection cost / life time		**€/m2*times**		**€ 1.62**	**€ 3.33**	**€ 0.14**	**€ —**	**€ 0.07**	**€ 0.09**	**€ 0.08**	**€ 0.23**	**€ 29.17**	**€ 0.69**
Total cost / life time		**€/m2*times**		**€ 8.38**	**€ 10.09**	**€ 6.90**	**€ 6.76**	**€ 6.83**	**€ 6.85**	**€ 6.84**	**€ 6.98**	**€ 35.31**	**€ 6.83**

Figure 10. Material cost of the nine different connection options.

Table 2. Labour cost for the nine connection alternatives.

Connection Option	Time Factor	Explanation
0. Conventional method	1	Reference value. Consisting of screwing secondary beams orthogonal to main beams, gluing shelf to beams, and stapling the shelf
1. Gluing	1.5	Gluing shelf to beams
2. Timber dowel	1	Drilling holes in beam and shelf (200 mm in between distance), attach dowel to beam using glue, attach beam + dowel to shelf using glue
3. Connection by fixation	2	Milling tapered groove in shelf, hammer beam in groove
4. L-connection	1.5	Both profiles need to be screwed on shelf (200 mm in between distance)
5. Z-connection	1.5	2 Z-profiles need to be screwed on shelf and beams, including L-profile, have to be slided in
6. Magnet connection (bottom)	0.5	Steel strip needs to screwed on bottom of shelf
7. Magnet connection (top)	0.5	Steel hollow core beams need to be clamped underneath the shelf
8. Vacuum connection	0.1	Only placing frame on top of shelf
9. Hoisting frame	0.2	Mounting the frame onto the formwork elements

Connection option	Material factor [–]	Time factor [–]	Ease of use	Workable for reuse	Waste factor [–]
0. Conventional method	1	1	1	1	1
1. Gluing	1.20	1.5	1	3	0.3
2. Timber dowel	0.82	1	1	3	0.3
3. Connection by fixation	0.81	2	0.5	2	0.7
4. L-connection	0.82	1.5	2	0.2	0.3
5. Z-connection	0.82	1.5	0.5	0.5	0.35
6. Magnet connection (bottom)	0.82	0.5	3	1	0.5
7. Magnet connection (top)	0.83	0.5	2	2	0.5
8. Vacuum connection	4.21	0.1	3	3	0.2
9. Hoisting frame	0.82	0.2	3	3	0.2

Figure 11. Total costs per lifetime expressed as a ratio of the cost of the conventional formwork system.

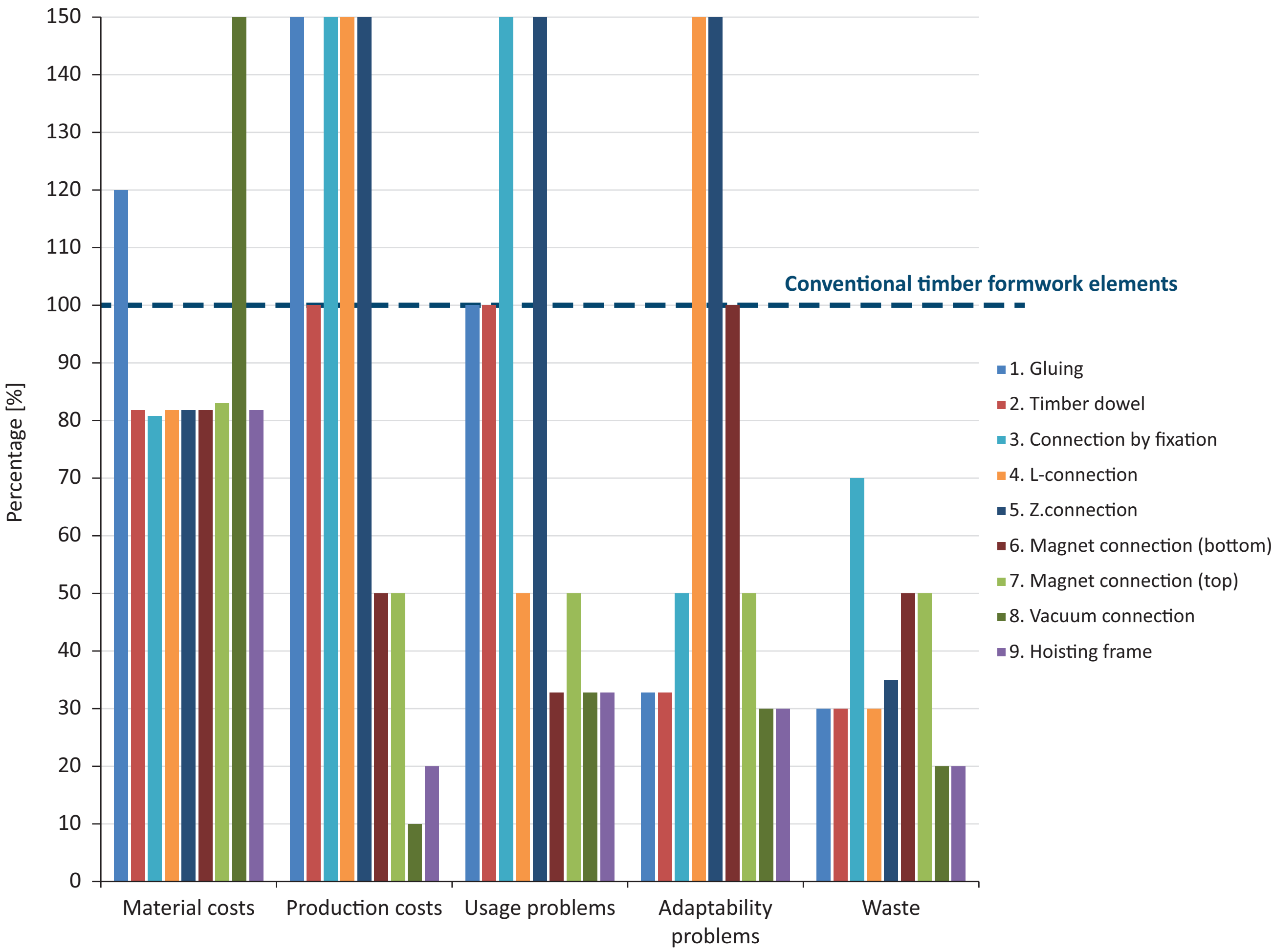


Figure 12. Visualisation of the total cost per lifetime for the different connection alternatives.

The results of Figure 11 are visualized in Figure 12. The dotted line shows the conventional method, being the reference value (100%). All bars lower than 100% are assumed positive.

7. Conclusion

This article is centred around a pilot project that applies reclaimed timber formwork for the construction of a new villa. As these formwork elements are only used a couple of times before being deemed unfit and discarded, they possess a huge potential for repurposing in building construction. While irregularities may make them less suited for visible building layers such as cladding, they do show some promise as part of the (sub)structure. Their thickness and high strength are well suited for solid timber construction. After all, most of the panels are discarded due to excessive seams or markings and not because of a failure in mechanical behaviour. To assess this behaviour, the project entailed the rigorous mechanical testing of the formwork panels, as presented in this article. As no detailed guides or codes exist on the reuse of formwork or even reclaimed timber, the Dutch Building Decree requires such tests. They show that the formwork elements have sufficient (remaining) load-bearing capacity to be applied in different structural applications.

Apart from the considerations about the structural performance of the timber formwork, the pilot project and studied cases provide some conclusions about material reuse. The main lessons are:

- Material reuse (and circular construction in general) requires a systematic and integrated approach.
- This approach should be flexible to adapt to the many unknowns related to material reuse.
- New types of collaborations are required, including the involvement of urban miners or other third parties, but also the more active involvement of contractors and engineers during the early design.
- Knowledge about circular construction and material reuse should be developed by all stakeholders in the value network, but also more horizontally in all layers of the involved companies or organisations.
- There is a need for more uniform definitions, guides, and codes.
- Using reclaimed materials reduces the embodied energy of a building and often saves material costs.

Logistics, planning issues, and additional efforts during the design and construction can, however, complicate the overall process. As such, the overall project budget can, in many cases, not be considerably reduced.

While this article does focus on one specific case study, its main contribution concerns the approach for assessment and redesign of the formwork. Reuse generally comes with a lot of unknowns about the origins and performance of reclaimed building components. This is especially the case for load-bearing products, whose performance ensures safety. This article shows a more statistical approach to reuse based on the availability of large amounts of similar non-building components. This shows a high potential for the repurposing of waste streams. Urban mining and the reuse of building components come with additional challenges. Materials often become available in small batches, making it less economically feasible to perform rigorous testing. Moreover, such components have often been used for long periods of time, sometimes in unknown conditions. This requires more extensive damage detection. Further research on the reuse of building materials can expand on this. Apart from more technological research, it will be important to map and develop solutions for the socio-economic barriers that currently hinder material reuse. Studies conducted in the Netherlands show that despite the increasing availability and large application potential in the construction sector, the use of reclaimed materials has not yet managed to scale up or break through. Financial and socio-cultural factors play an important role in this, such as habituation and the lack of additional comfort to compensate for the higher initial cost. The central case study of the circular house in Amsterdam shows that high percentages of reuse are possible for the construction of new buildings, but also depend on socio-economic factors and in this case the involvement and initiative of the building owner.

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Conflict of Interests

The authors declare no conflict of interests.

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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.

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Article

Renewable Energy Communities as a New Actor in Home Energy Savings

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Abstract
Renewable energy communities (RECs) might be an interesting new stakeholder in stimulating home energy-saving efforts by tenants and homeowners due to their potential of raising awareness locally and gaining public support for low-carbon energy and energy-savings projects, because RECs are often locally sited, in close social proximity of residents, and are already part of local structures and share local institutions. This comes with many benefits since they already have a reputation locally, a social history with the local community, and can be trusted by the latter. This makes them potentially better suited than other—often less-trusted—parties (i.e., government and business companies) to use their agency to encourage sustainable change. The article builds on empirical data from the EU Horizon 2020 project REScoop Plus, using a mixed-methods research approach, including desk research, expert interviews, validation workshops, and multiple surveys among RECs in six EU member states about energy-saving actions implemented, and their effectiveness in terms of raising awareness, influencing the intention to save energy, and actual energy-saving behaviour. This article provides more insight into the assessment of actions and measures for coaching householders to achieve energy savings and low carbon goals. In addition, it shows the potential of using RECs as a new strategy to address home energy savings in the current housing stock, including options to improve the energy performance thereof.

Keywords
citizens' initiatives; community energy; energy conservation; energy transition; home energy savings; renewable energy communities; societal self-governance

Issue
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1. Introduction

In the challenge of renovating the existing housing stock in the built environment, increasing its energy performance and improving residents' participation in neighbourhood renovation activities is crucial. Both tenants and owners should reconsider their energy use and the energy production of their dwelling or should be encouraged by agencies to do so. An actor that is easily overlooked is the self-organisation of citizens who can help each other to live "energy-neutral." These include, among others, joint housing projects (Tummers, 2021), associations of tenants or owners in a particular building or neighbourhood, eco-villages, and so-called renewable energy communities (RECs). In European legislation (see Section 3), RECs are legal entities that have as a primary purpose to provide environmental, economic, or social community benefits to its members or shareholders by engaging in renewable energy activities on a not-for-profit basis. In practice, the benefits of their activities do not just concern their members or shareholders but also the larger community.

2. Research Questions

In this article, the activities of RECs that are linked to the improving energy performance of homes in the existing housing stock are presented. In particular, we discuss the advantage of RECs as an agent over others that stimulate households to save energy or invest in renewable energy. Behavioural determinants of households consuming energy can be targeted with actions or interventions—i.e., as "policy instruments"—to induce change or to change the conditions that influence how energy is consumed. Creating zero-energy homes is not merely a technological or economical challenge; it also contains a human factor. Creating zero-energy homes also calls for a change in the behaviour and the energy practices of final energy users (i.e., householders). This involves the consumption of energy in more rational and efficient ways. In the residential sector, this behaviour of tenants and homeowners is crucial. In particular, households consume energy and can be targeted with the aim of behavioural change, leading to lower volumes in energy demand. Research on energy saving tends to be within the context of low-carbon behaviour-change activities (Howell, 2012).

Historically, households are considered a target group that is difficult to reach or to persuade (Bressers & Ligteringen, 1997). RECs are increasingly considered important players in renewable energy and energy-saving efforts (Coenen et al., 2017). The hypothesis that is central to this article holds that extending the role of RECs as a new stakeholder in the energy renovation of homes and, more in general, home energy savings, has the potential to reach the difficult target group of tenants and homeowners. Establishing new RECs or getting existing ones involved would raise the level of participation of inhabitants in neighbourhood renovation activities and encourage more sustainable lifestyles. For these reasons, RECs can be considered a new and promising strategy to improve energy performance in the current housing stock.

In this article, three questions are addressed:

1. How do RECs encourage their members and (other) households to save energy?
2. To what extent are RECSs capable of effectively encouraging their members and (other) households to save energy?
3. To what extent could the potential involvement of RECs be considered a new strategy to improve the energy performance of the current housing stock?

To answer the first question, Section 3 discusses what RECs are and how they relate to stimulating home energy-savings. In Section 4, arguments are discussed on why RECs as agents of change are particularly suited to influence home energy savings. In Section 5, types of energy-saving instruments and actions are presented. This is confronted with the potential of RECs to use these mechanisms. Section 6 addresses the research approach and methods of the present study. Section 7 presents an overview of energy saving actions implemented by RECs. And in Section 8, the empirical results and insights are presented, highlighting the use of actions and measures of home energy savings. To answer the second question, the effectiveness of several dedicated energy-saving measures is discussed. In the concluding section, the research questions above are answered and we reflect on the potential advantages of a larger involvement of energy communities as a new strategy to increase the energy renovation rate of the existing housing stock.

3. Renewable Energy Communities

In the academic literature on community energy and policy practice, citizen energy initiatives go by very different names, like citizen-led renewable energy initiatives, local renewable energy organisations (Boon & Dieperink, 2014), local low-carbon energy initiatives (Warbroek et al., 2019), or renewable energy cooperatives (REScoops; REScoop.eu, 2022). The academic debates surrounding the growing academic field of energy communities contribute to "a bulwark of empirical examples, theoretical reflections and methodological tools" (Creamer et al., 2019, p. 1). Here, we follow the concept of "energy communities" as it was introduced through the "Clean Energy for All Europeans" package by the EU in its legislation, notably as: (a) "citizen energy communities" (CECs; Article 2 of the Electricity Directive) and (b) "renewable energy communities" (Article 2 of the Renewables Directive). Article 2 of the Renewables Directive defines RECs. "Renewable energy community" means a legal entity:

1. Which, in accordance with the applicable national law, is based on open and voluntary participation, is autonomous, and is effectively controlled by shareholders or members that are located in the proximity of the renewable energy projects that are owned and developed by that legal entity;
2. Whose shareholders or members are natural persons, small and medium-sized enterprises, or local authorities, including municipalities;
3. Whose primary purpose is to provide environmental, economic, or social community benefits for its shareholders or members or for the local areas where it operates, rather than financial profits.

The definition of CECs (Article 2 of the Electricity Directive) is quite similar to the one on RECs. The second and third bulleted issues are the same as the Renewable Energy Directive. The first issue holds that the autonomy principle is absent when compared to the definition of RECs. Where community initiatives seeking to produce, distribute, and consume energy locally are not a new phenomenon, the definition of CECs is the explicit recognition that community energy is not just about jointly producing renewable energy.

Energy communities are also engaged in other energy services and activities (Seyfang et al., 2013), such as persuading their members to conserve energy

(Coenen et al., 2017; Hoppe et al., 2016, 2019; Oteman et al., 2014; van der Schoor & Scholtens, 2015). Promoting home energy savings goes well with the primary purpose of providing benefits by RECs or CECs. When home energy savings are successfully promoted the energy savings create economic benefits including reduced energy bills for households (REScoop.eu & ClientEarth, 2020). Social benefits of the activities promoting energy-saving include the provision of different services (e.g., energy advice) to members including investment in energy efficiency and energy poverty. In addition, the energy-saving promotion provides environmental benefits including the reduction of greenhouse gas emissions. In the present article, the main focus is on measures that target influencing the curtailment and efficiency behaviours (including investment and adoption decisions) of tenants and homeowners. Historically, RECs and related NGOs have been stimulating home energy savings going back to the previous century. For example, in the UK, the Energy Savings Trust was established and served as an intermediary focusing on promoting energy-saving behaviours. It did so at a national level by delivering services to other (local) community energy organisations and households in terms of networking, supporting, and funding (Seyfang et al., 2014). It also created websites and online repositories that local community energy organisations could use to demonstrate energy savings and the lowering of carbon emissions (Hargreaves et al., 2013). Brummer (2018) shows that both in the UK and the US, community energy organisations are active in educational activities providing knowledge on energy-saving behaviours, combined with raising awareness for issues connected with energy consumption, such as climate change. Furthermore, Heiskanen et al. (2010) observed community energy organisations running virtual energy-saving platforms. More recently, RECs have also started to use high-tech solutions to stimulate home energy savings, e.g., through the use of smart grids, virtual power plants, and smart meters (van Summeren et al., 2020).

4. The Potential of Renewable Energy Communities to Influence Citizen Energy Saving

There are specific normative reasons for the existence of RECs, linked to objections against practices in current energy markets, and more in general the (fossil fuel and nuclear-fed) centralised energy system model (Coenen & Hoppe, 2021). According to the Renewable Energy Directive, the EU wants RECs and energy-active citizens to become agents of change in the sustainable energy transition in all EU member states and play an instrumental role in the low-carbon energy transition (Directive 2018/2001, 2018). The potential of RECs to stimulate home energy savings and renewable energy investments of tenants and homeowners lies in several factors where they, compared to other organisations (mainly from the public and private sector), are fairly well-positioned. When compared to other organisations (like local government, distribution system operators, or energy companies) they can potentially deliver services more efficiently for several reasons (Coenen & Hoppe, 2016; Coenen et al., 2017). Here, three groups of arguments are distinguished, respectively related to social embeddedness, community advantages, and trust and social acceptance. Social embeddedness in communities and social structures makes a difference with other agents:

- RECs are already embedded in social structures, and therefore have close ties with their customer groups and have direct contacts with consumers regarding energy saving (Hess, 2018);
- They can raise awareness among both the larger community and individual members to stress the importance of energy-saving. Because of their social embeddedness in local communities, they are likely better equipped to reach out to target groups than other agents would (Bauwens & Defourny, 2017; Dóci et al., 2015; Hewitt et al., 2019);
- They can set energy saving as a social norm within the community (Abrahamse et al., 2005).

Energy communities have the advantage over other agents of being a (local) community:

- RECs can organise energy-saving expertise dissemination at the community level, e.g., by organising workshops, working groups, or setting up an “energy library”;
- Through their critical mass, they can build energy-saving expertise to share with members and the community (Bauwens, 2016);
- They can define and distribute the available capacity of renewable energy as a common resource in the community (Becker et al., 2017; Wolsink, 2012);
- They can better deal with NIMBY problems (the phenomenon of people objecting to the siting of something perceived as unpleasant or hazardous in the area where they live, especially while raising no such objections to similar developments elsewhere) related to aspects that have to do with siting (renewable) energy plants by balancing spatial, social, economic, and environmental interests in the community (O’Neil, 2020).

RECs, because they are a social community, have the advantage of generating more trust and social acceptance over other agents:

- They are viewed as a reliable partner to give advice, supply energy systems and appliances, and make people more willing to take energy-saving investment risks (Walker et al., 2010);

- They cannot only give personal and tailored assistance to members to develop a personal capacity to save energy but are trusted by the target group;
- They can easily cooperate with local stakeholders and have a different position because of their non-for-profit and idealistic goals (Hoppe et al., 2015; Warbroek et al., 2019; Warbroek, 2019);
- They can tailor energy-saving measures to where it is effective, while also addressing related social issues like energy poverty and justice (Feenstra & Hanke, 2021).

5. Types of Energy-Saving Instruments and Actions

Although energy communities are not governmental organisations, there is an analogy between the activities of RECs allowing their members to save energy and invest in renewable energy and the use of public policy tools. However, public policy is made by governments and organisations which act on behalf of governments. Public policies are legitimised by elected politicians' decision-making. Governments use policy tools or instruments to influence citizen behaviour and achieve policy goals (Dahl & Lindblom, 1953). Because tenants and homeowners are not a well-organised target group that the government can address, compared to business companies, policy instruments like voluntary agreements and permit systems are not suitable. So, actions aiming at energy savings of members, or the broader community of energy communities have to focus on influencing individual decisions and action. Schneider and Ingram (1990) distinguish five reasons why people are not taking action that can be addressed by policy: People may believe the law does not direct or authorise them to take action; they may lack incentives or the capacity to take the actions needed; they may disagree with the values implicit in the means or ends, or the situation may involve such high levels of uncertainty that the nature of the problem is unknown; it is unclear what people should do or how they might be motivated. Policy instruments address these problems by: (a) providing authority, (b) providing incentives or capacity, and (c) using symbolic and hortatory proclamations. Next, Schneider and Ingram (1990) distinguish five types of policy instruments:

1. Authority tools, which are statements backed by the legitimate authority of the government that grant permission, prohibit, or require action under designated circumstances;
2. Incentive tools are tools that rely on tangible payoffs, either positive or negative, to induce compliance or encourage utilisation;
3. Capacity tools are tools that provide information, training, education, and resources to enable individuals (or groups and agencies) to make decisions or carry out activities;
4. Symbolic and hortatory tools motivate people to take policy-related actions based on their beliefs and values. A hortatory is a person or thing that strongly requests someone else to take a particular action;
5. Learning tools that promote learning about the problem and the knowledge and uncertainty about both the problem and the action to be undertaken.

RECs cannot use all types of policy instruments. Real authority tools are not relevant to the energy community, but many actions of energy communities are backed up by their legitimacy as democratically organised, voluntary membership organisations. For direct influence, they need rewards to motivate households with individual tangible payoffs. Indirectly, RECs can influence the context in which the energy-saving decision is taken by using capacity tools. Through information or knowledge tools, tenants and homeowners can be persuaded to alter their energy consumption behaviour because they are confronted with new facts, information, or knowledge. The situation in itself has not changed. Regardless of the information (knowledge, arguments, and moral appeal) that is transferred, or through which mechanism (encouragement, persuasion, etc.), the change in behaviour is still voluntary. This also means that the provision of information does not always lead to a change in energy-use behaviour, because it is up to the REC member or other tenant or homeowner to act based on the information. However, a recent study revealed that financial motives seem overrated and communal motives underrated concerning involvement in community energy-saving actions (Sloot et al., 2019).

The relation between information and behaviour brings us to another strand in literature next to policy science, namely behavioural intervention strategy, which has a background in environmental psychology (Abrahamse et al., 2005; Frederiks et al., 2015; Gardner & Stern, 1996). If the assumption of how a policy instrument works is based on behaviour, there is a lot of resemblance between the two strands of literature. In psychology, interventions are actions performed to bring about change in people. There is one type of intervention strategy that is directed towards activities to modify behaviour. Behavioural interventions may be aimed at, viz., (a) voluntary behaviour change, by changing individual knowledge and/or perceptions; and (b) changing the contextual factors (i.e., the pay-off structure) which may determine households' behavioural decisions (Abrahamse et al., 2005). In this article, we focus on what can be called micro-level factors and not the macro-level or structural factors. These factors, together with institutional factors and cultural developments, influence the motivation, preferences, attitudes, opportunities, and abilities of households to save energy.

Behaviours related to household energy saving can be divided into two types of behavioural change (Gardner & Stern, 1996): (a) efficiency behaviour, as a one-shot action or decision to save energy (for instance buying energy-efficient equipment or the thermal insulation of houses); and (b) curtailment behaviour, with repetitive efforts to save energy (for instance lowering the temperature in a room by changing the thermostat or deciding to dry the laundry outdoors in the garden instead of in an electric drying machine; Steg et al., 2018). Abrahamse et al. (2005) use a taxonomy for behaviour change interventions first issued by Geller et al. (1990) which addresses antecedent and consequences strategies. Antecedent strategy attempts to influence one or more behavioural determinants prior to the performance of energy-saving behaviour. Examples are goal setting, commitment, information provision, and modelling. Another example—well practiced among RECs—pertains to the promotion of energy-saving advice services giving pledgees the information to take action themselves (Bomberg & McEwen, 2012; Heiskanen et al., 2010). On the other hand, the consequences strategy tries to influence behavioural determinants after the occurrence of the energy-saving behaviour by providing consequences feedback on the outcome after the occurrence of the behaviour. Consequence strategies—i.e., offering rewards, or providing feedback—are based on the assumption that the presence of positive or negative consequences will influence behaviour because it will make energy-saving more attractive. Candelise and Ruggieri (2020) observed RECs in Italy using energy bills to stimulate home energy savings among their members.

6. Research Methodology

The empirical data in this article is taken from the EU's Horizon 2020 project REScoop Plus (2016–2018; Chalkiadakis et al., 2018; Coenen et al., 2017) which addressed RECs using their agency to encourage household energy savings and household renewable energy investments. The main goal of the project was to research how to improve energy savings and household renewable energy investment stimulation strategies as an activity for REScoops across Europe. REScoops are defined as "groups of citizens who organise themselves to collectively take action to foster the use of renewable energy and increase energy efficiency standards" (REScoop.eu, 2022), and can be considered to serve as a good example for RECs.

To answer the two research questions central to this article, different research strategies are used applying a mixed-methods approach. For the first question—how do RECs encourage their members and (other) households to save energy or invest in renewable energy options?—an exploratory research approach was used to map the incentives, measures, tools, and approaches the researched REScoops use. First, an inventory of was made of interventions and strategies used by seven REScoop federations from six EU nation-states, all organisations in the project consortium (the REScoops in the project consortium are Coopernico, in Portugal; Enostra, in Italy; Ecopower, in Belgium; Enercoop, in France; EBO, in Denmark; SEV, in Italy; and SOMenergia, in Spain). The inventory work presented was based on desk research (organisation documents and organisation websites), a literature review, and primary data collected using an expert survey. These seven experts were appointed by their REScoop organisations and were contacted, asked to complete a questionnaire, and produce a factsheet about dedicated actions they use to stimulate home energy savings among their members. Based on the desk research and following the expert survey and collection of the factsheets, the appointed experts were interviewed (via Skype). In addition, two online expert workshops were organised to discuss and validate the (preliminary) results. The main purpose of the interviews was to gain more insights into the experiences, background, context, and use of actions and dedicated measures. Based on the inventory, eight in-depth illustrative case studies were conducted to shed light on the actual meaning and experiences with the implementation of particular (combinations of) actions and measures.

To answer the second research question—to what extent are RECSs capable of effectively encouraging their members and (other) households to save energy?—first, energy savings behaviours, energy consumption, and indicators of energy savings needed to be measured. Secondly, it had to be assessed whether and how these could be related to the actions and measures implemented by the REScoops. In addition, (anonymised) longitudinal energy consumption data were obtained from the REScoops in the project and for some control groups with different suppliers. Due to the availability of data, actual consumption data focused on electricity consumption (excluding gas and other sources needed for heating of homes and tap water). Next to longitudinal data sets additional data were obtained from REScoops (or companies performing energy service management to REScoops) about members and non-members clients (consuming energy supplied by REScoops, or persons otherwise connected as non-clients) to the REScoop community about their energy use (Sifakis et al., 2018, 2020).

Two rounds of surveys were conducted among REScoop members, non-members clients (consuming energy supplied by REScoops but not having obtained REScoop membership), or persons otherwise connected to the REScoop community and others. First, in the spring and summer of 2017, a first round of surveys was conducted among six REScoops in five EU member states (N = 10,585). Second, in the spring and summer of 2018, a second round of surveys was conducted among seven REScoops in six EU member states (N = 7,556). Whereas the 2017 survey focused on general REScoop characteristics and home energy savings, the 2018 survey paid more intention to the implementation of several dedicated REScoop measures (interventions). The behavioural analysis focused on behaviour related to the use of both electricity and energy sources used for in-home heating.

Figure 1 below summarises the research strategy in the REScoop Plus project to determine the influence of

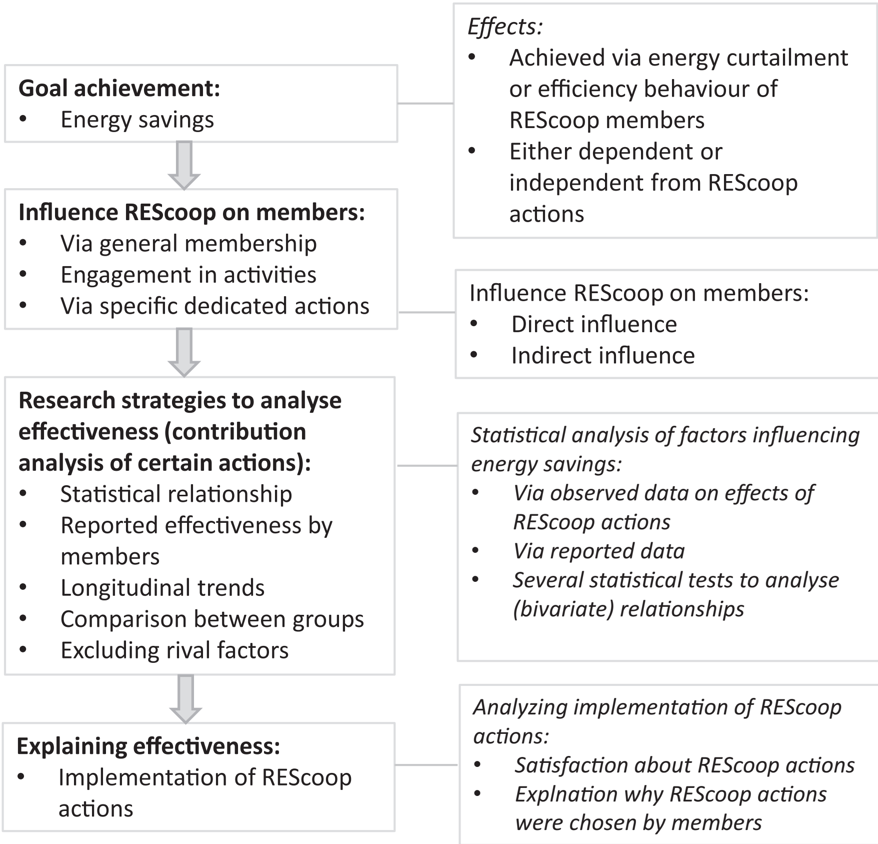

Figure 1. Research strategy to determine the effectiveness of REScoops to encourage their members to save energy. Source: Adapted from Coenen and Hoppe (2018).

REScoop on its members. Here, effectiveness means that home energy savings are reached due to the actions of the energy communities or membership and not through other factors (i.e., home energy savings can be attributed to REScoop actions and activities).

7. Overview of Actions of Energy Communities

In this section, the question "how do energy communities encourage their members and (other) households to save energy?" is addressed. Figure 2 presents an overview of actions and dedicated measures implemented by six REScoops studied in the REScoop Plus project (Coenen & Hoppe, 2016). The overview is based on the dimensions of energy behaviour (with the extremes of the dimension as either curtailment of efficiency behaviour) and type of strategy (either antecedent or consequence strategy). An overview of several illustrative specific and dedicated measures used by these REScoops in the project is presented in Table 1.

Based on the classification defined in Section 3, Figure 2 shows that:

- RECs use a wide range of measures to encourage members and non-members to save energy. The majority of measures use antecedent strategy rather than consequence strategy, and curtailment behaviour appears to be targeted more than efficiency behaviour.
- In terms of "policy instruments," the majority of measures can be seen as capacity tools to inform target groups about the benefits of energy-saving and to prepare how to engage in energy-saving behaviour. Examples include the use of energy ambassadors, awareness-raising events, inspiration sessions, and using mock homes with state-of-the-art energy-efficient technology as a role model. Incentive tools (like rewards or competitions) are also observed but appear less frequently. The measures observed also include technological tools like energy communities lending infrared heating meters to observe thermal bridges in their homes, smart meters to measure and provide feedback on energy consumption to householders, and ICT interfaces to support energy service delivery—including tariffs and billing—and information to households (as "clients" and energy community member at the same time).
- The mapping exercise also revealed integrated measures that include a multitude of actions and contain both antecedent and consequence strategies. Examples include the "Dr Watt" training programme of the French REScoop Enercoop (see Table 1), which contain both capacity and incen-

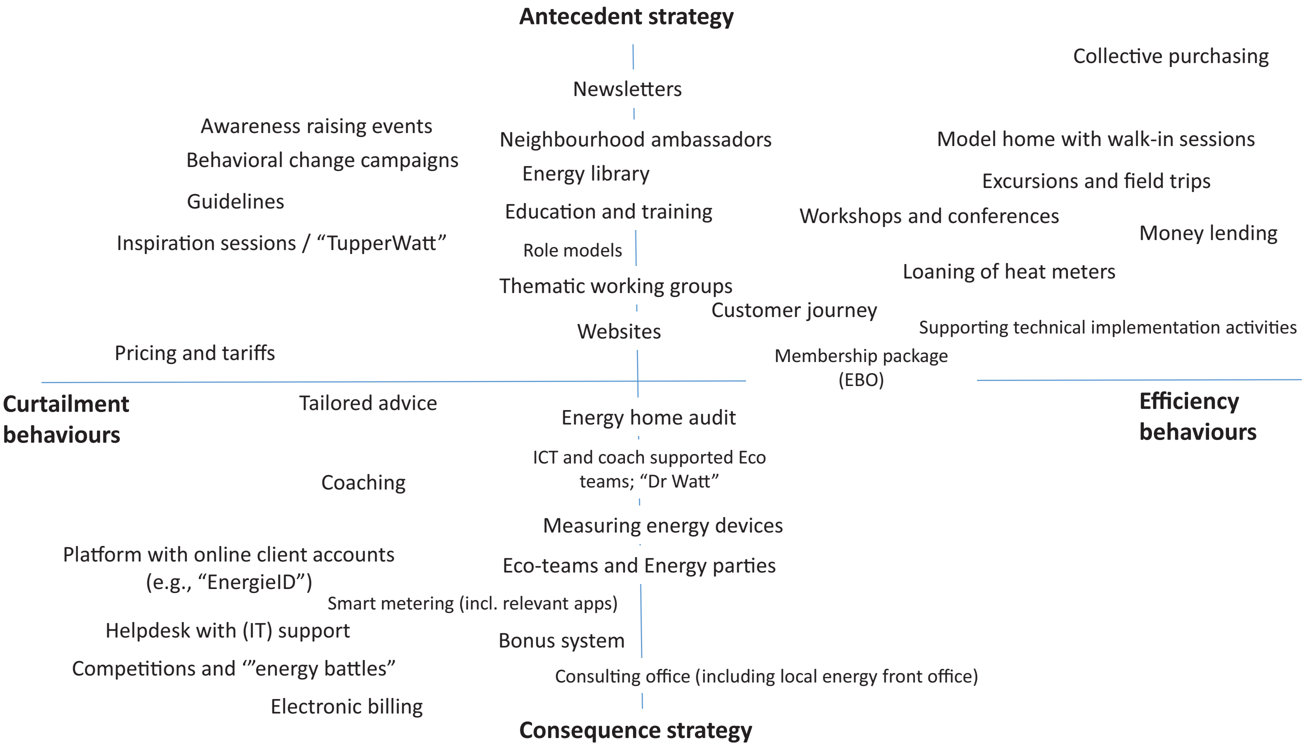

Figure 2. Classification of actions and measures implemented by REScoops to stimulate home energy savings. Source: Adapted from Hoppe and Coenen (2021).

tive tools, yet also uses technological tools in support (i.e., ICT, home metering equipment, and a smart meter). Table 1 illustrates several specific dedicated measures used by energy communities.

8. Effectiveness of the Actions RECs Implement

In this section, the question "to what extent are energy communities effective in encouraging their members (and other households) to save energy?" is addressed. Discussing the effectiveness of membership is particularly interesting from the perspective of this article. However, when members of the RECs save energy, this does not automatically mean that this is due to actions of the REC or the influence of simply being a member. Furthermore, if RECs influence their members (or clients), they have to distinguish between different types of influence and actions of the former. A distinction can be made between general membership, being involved in activities, and the influence of specific actions and dedicated measures. The latter concerns interventions in which members participate or through which they are addressed. These types of measures resemble actions that could have been taken by other agents. Unspecified measures entail the generally presumed influence of being (indirectly) exposed to REC actions and information. This is not unique for REC members. Also, other agents might take more unspecified measures not linked to a specific behavioural change of the tenants and house owners targeted. However, membership influencing REC members to attain certain goals (like energy savings) is more unique for RECs. Membership potentially influences energy saving for several reasons. Becoming a member (and/or customer) can be seen as making an informed choice; in other words, one chooses deliberately to engage in using green energy.

The reason to become a member can be motivated by environmental or sustainability concerns or by pragmatic financial or technical reasons, like the expectation to receive better service provision or more comfort. If one obtains REC membership, one receives information on the importance of saving energy and how to do so (Bauwens, 2016). This could mean that the information level of the REC members on the importance of renewable energy and possibilities to save energy increases after obtaining membership, which could lead to a higher knowledge level (concerning renewable energy and energy-saving options). However, more information or awareness does not automatically mean that one also engages in actions to attain a certain goal (like saving a certain amount of energy). Here, it is assumed that it is easier for energy communities to influence members who are more concerned about personal finance and actively engaged in their energy community, for instance, because they hold shares in their energy community or visit meetings it organises. This is a particular subset of REC members, i.e., the subset of engaged members (Coenen & Hoppe, 2018).

Table 1. Overview of illustrative specific dedicated measures used by energy communities.

Measure	Implemented by REScoop (Country)	Description
Dr Watt	Enercoop (France)	An online tool that comes with an offline training course to help consumers self-diagnose their electricity consumption. The approach seeks to make households more aware and to increase understanding of home electricity consumption, but also provides tailored advice.
TupperWatt	Enercoop (France)	TupperWatt meetings are organised for households who want to be more involved in energy community activities and put citizens at the centre of energy issues. This type of event—inspired by "Tupperware parties"—fits the general communication strategy of Enercoop: not too much advertising and creating social links within the community while sharing experiences.
EnergieID	Ecopower (Belgium)	A SaaS ("software as a service") platform to support households to understand and manage their energy consumption as well as renewable energy production (via solar panels). Customers sign up with an account on EnergieID and, every month, they fill in their energy consumption data. Then, together with the helpdesk service of Ecopower, the energy bills and energy consumption are analysed and discussed with customers (including Ecopower members), either by phone or by email.
DH Package	EBO (Denmark)	District heating (DH) package, or *pakkeløsning* in Danish, is a conversion package for homeowners to switch from a gas grid connection to a (sustainable) DH system grid connection. It includes four steps: (a) a home visit and an agreement of where the district heating unit is going to be installed, (b) the establishment of a heat service line to the consumer's house and restoration of the garden, (c) the removal of the consumer's existing heating source, and (d) the delivery and installation of a new district heating unit. Before the measures are taken, unburdening of the homeowner takes place. Afterward, the performance of the installed DH system package is monitored periodically. *Pakkeløsning* entails an integrative DH installation.

Source: Based on Hoppe and Coenen (2021).

8.1. Results From the REScoop Plus Project

Figures 3 to 7 present the key results from the REScoop Plus project on REScoops and home energy savings of their members.

Respondents indicate average energy savings in the range of 4–6% (Figure 4). Of those who measured their energy consumption, about 21–22% indicate having saved at least 10% energy, and between 9–10% indicate having saved at least 20% (Figure 5; Coenen & Hoppe, 2018).

To determine whether REScoops, without specifying how, influenced their members on energy saving, either actual or perceived, the reported influence by the members is presented in Figure 6.

The surveys indicated that REScoop members undertake many (individual) energy-saving actions like lowering the thermostat or taking shorter showers (Figure 7).

Energy savings are considered to become more important after joining a REScoop (or at least for four out of six REScoops surveyed, i.e., Ecopower, Enercoop, Enostra, and SOM Energia), but, as Figure 6 shows, between 20% and 52% of the respondents attribute home energy-savings to their REScoop (and, if so, this mostly concerns efficiency behaviour, in particular switching conventional lighting to LED lighting). One obvious explanation for the influence on energy-saving behaviour would be that REScoop members had already started saving energy before they became a member. Moreover, those people already showing a high degree of pro-environmental behaviour also seem to get involved in RECs (i.e., showing reverse causation; Sloot et al., 2018).

In the surveys, members were asked about their energy-saving actions and how these relate to the actions of the REScoop. Only a part of those respondents—e.g., 18% of the respondents from Enercoop and 36% of respondents from Ecopower; for energy curtailment behaviours this is considerably less (15–17%) than for energy efficiency behaviours (20–30%; Hoppe et al., 2019)—however, indicates that (individual) energy-saving actions can be attributed to their REScoop (Hoppe et al., 2019). Overall, members of REScoops were found to be committed to saving energy in terms of attitude, intention, and actual behaviour. They show high engagement with various energy-saving behaviours (both curtailment and energy efficiency behaviours) and demonstrate more individual energy-saving behaviours than those who are not members of REScoops (or other RECs). The longer the energy community membership, the more knowledge is gained, and the more energy-saving behaviours are performed. This relates to visiting

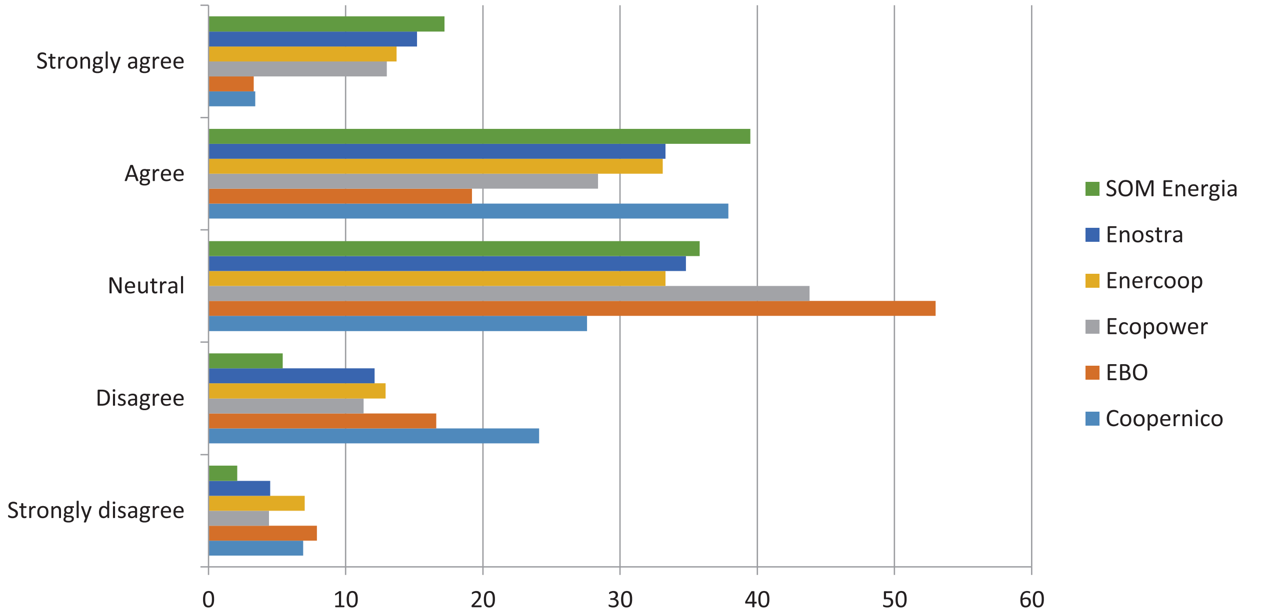

Figure 3. Response, in %, to the 2018 survey item "After having joined a REScoop, energy savings have become more important to me" by REScoop.

more energy community meetings (or workshops) and activities within integrated (i.e., combination of) measures (Hoppe et al., 2019).

The energy consumption data obtained from the REScoops allowed conducting longitudinal time series trend analysis that revealed several important findings (Sifakis et al., 2018, 2019). The key finding is that implementing energy efficiency interventions of various types, such as technical support, special tariffs, energy generation schemes, and smart meters, leads to substantial energy reductions of more than 10%, cumulatively (Sifakis et al., 2020). More specifically, joining a REScoop was found to lead to a more than 20% reduction in electricity consumption. Also, installing solar panels on one's home reduces REScoop members' electricity demand by more than 45%, with those having

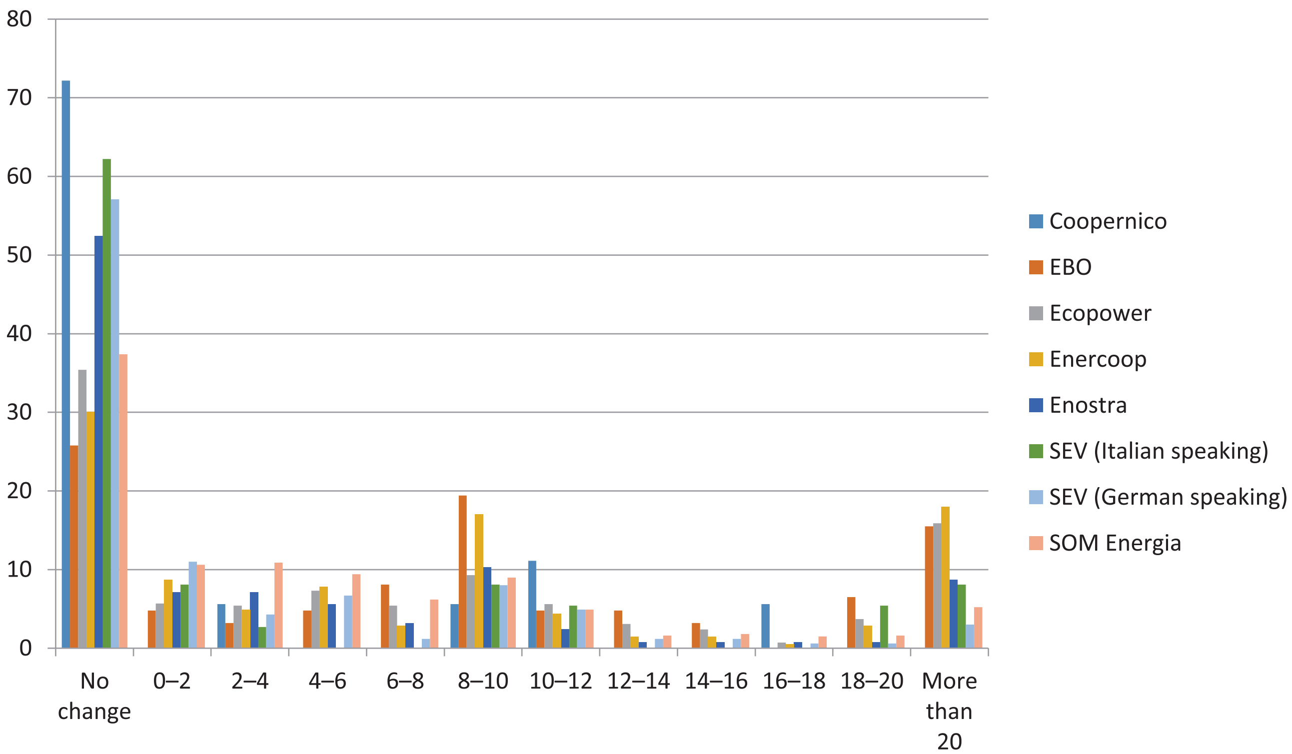

Figure 4. Reported energy savings by REScoop, in % (2018 survey).

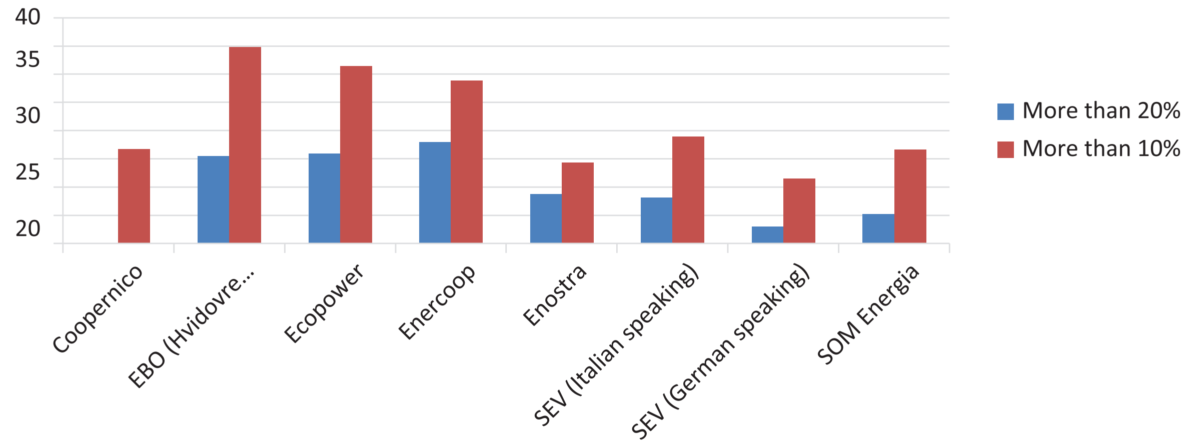

Figure 5. Reporting of more than 10% and 20% energy savings realised, in % of respondents, by REScoop (2018 survey).

solar panels installed at home consuming nearly three times less grid-supplied electricity than those who do not have solar panels installed at home. At Ecopower, no less than 43% of the respondents were found to be prosumers, generating their green power locally. The share of Ecopower members having installed solar panels at home has also increased sharply over recent years, encouraged by Ecopower's agency (Sifakis et al., 2020). Furthermore, energy efficiency interventions of various kinds, such as technical support, special tariffs, energy generation schemes, and installing smart meters, statistically correlate (positively) to substantial reductions in energy consumption.

To nuance the conclusion that only a part of those respondents indicates that (individual) energy-saving actions can be attributed to a REScoop, we have to look at so-called specific measures that concern interventions in which members participate or through which they are addressed. In particular, the use of specific integrated measures (including both antecedent and consequence strategy, such as the Dr Watt intervention by Enercoop) can be considered as fairly effective, resulting in considerable energy savings. The longitudinal data analysis (Sifakis et al., 2020) showed that those who register with EnergieID save 10% in energy consumption, those who partake in Dr Watt training sessions at Enercoop

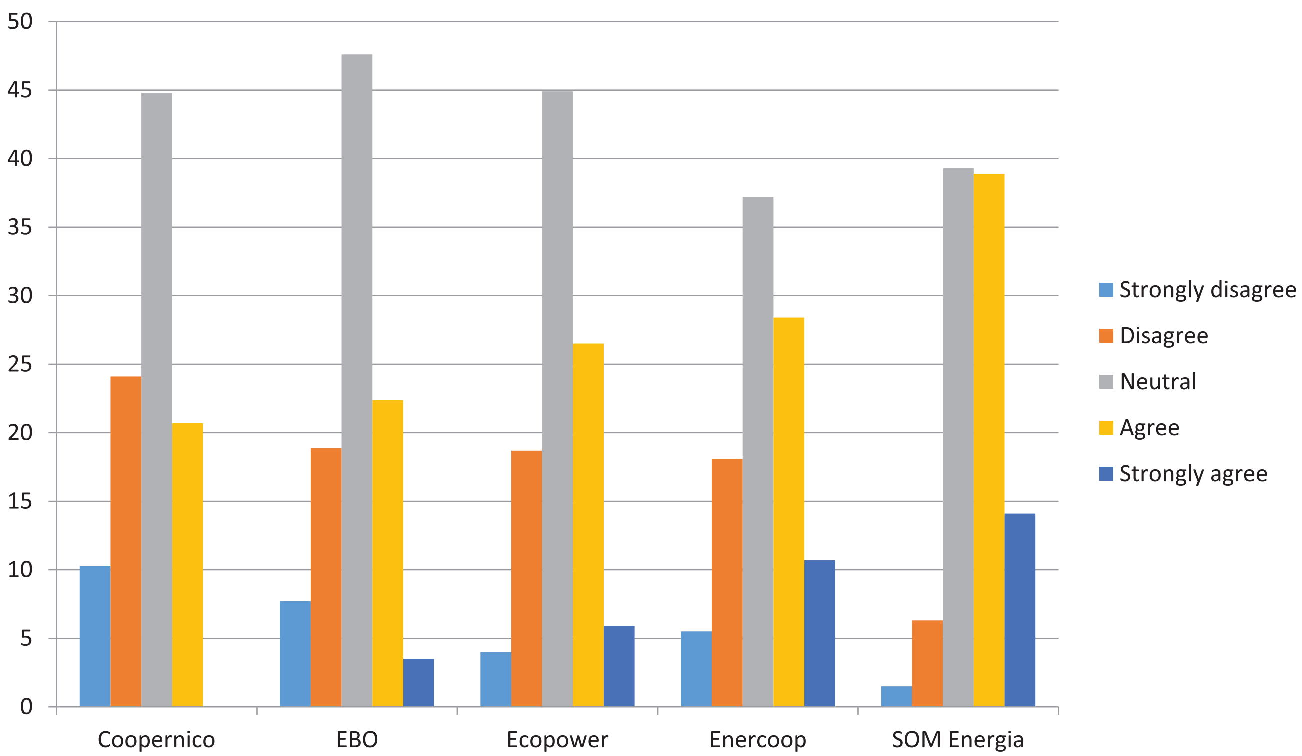

Figure 6. Response, in %, to the 2018 survey item "My REScoop has contributed to that I save more energy in my household" by REScoop.

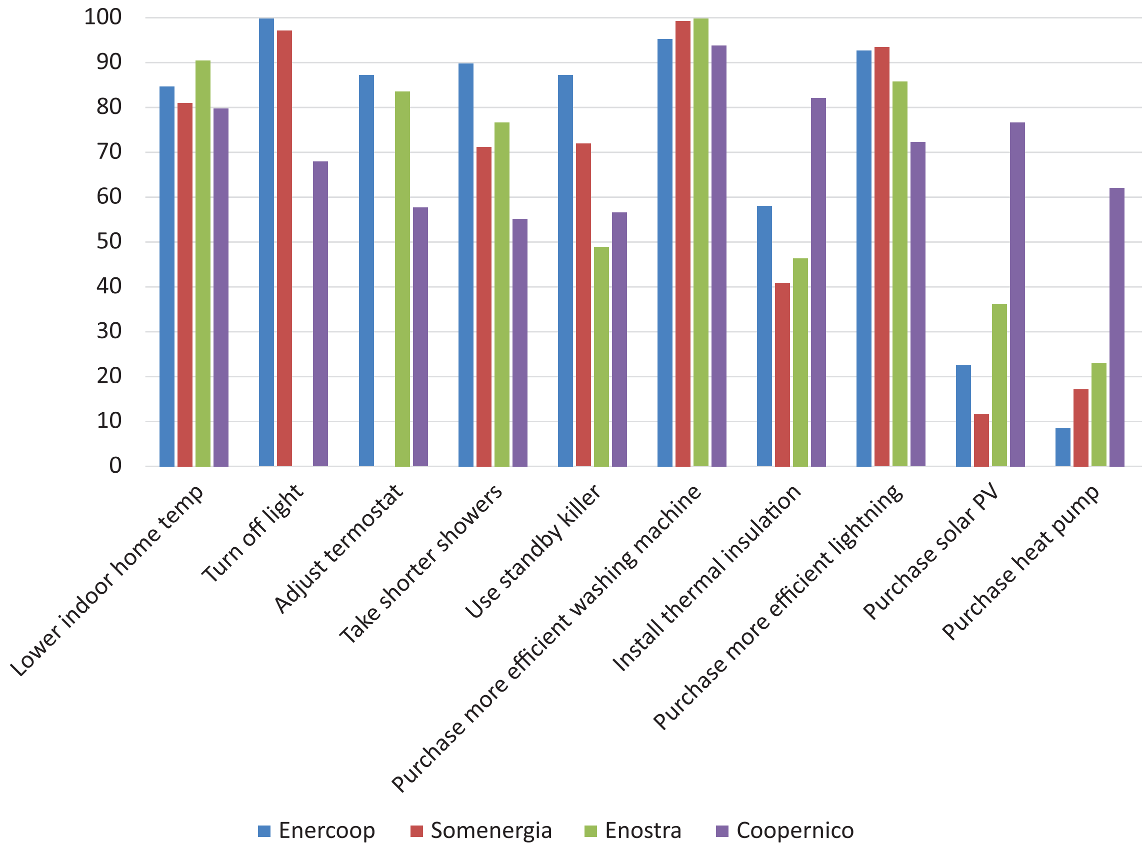

Figure 7. Response, in %, to the 2018 survey item about engagement in particular energy-saving behaviour (per REScoop).

were found to consume 13% less electricity than others who did not partake, and those who had smart meters installed were found to consume over 26% less electricity. The longitudinal data analysis results should, however, be interpreted with caution as limitations in the data collection (mostly due to challenges to the availability of reliable data) caused the research to only modestly address (internal and external) validity issues. Installing a solar panel system might, for instance, create a distorted image concerning the influence of smart meter installation on total household electricity consumption.

The conclusions of the longitudinal data analysis (Sifakis et al., 2020) correspond to the survey results. In the 2017 survey, several specific energy measures and tools implemented by REScoops (i.e., Dr Watt training sessions, personal advice, or EnergieID) were found to be significantly and positively related to energy savings (since becoming a REScoop member; Coenen & Hoppe, 2017). Moreover, users were generally satisfied with them. EnergieID users also indicated increased importance and contribution to energy savings. Increasing portions of the respondents indicated realising energy savings (e.g., EnergieID: from 20% in 2017 to 30% in 2018 at Ecopower; Dr Watt: from 3% of Enercoop members to 37% in 2018). Results from the 2018 survey revealed that specific measures using platforms (along with related informational actions) were found to statistically correlate positively to reported energy savings, whereas sole informational actions (e.g., TupperWatt, or saving tips on the energy-saving Wiki) only influenced the intention to save energy, but no actual energy savings (Coenen & Hoppe, 2018).

9. Conclusions

When facing the challenge of the large-scale refurbishment of the existing housing stock, increasing resident participation in neighbourhood renovation activities is of crucial importance. Establishing RECs in neighbourhoods or housing projects in general, or more specifically in large-scale energy renovation projects, could potentially serve as a means to increase citizen participation rates. Furthermore, taking a value perspective, this increased level of participation could potentially come with more democratic rules for decision-making in these projects, giving residents a firm say and making these processes more transparent. RECs are based on democratic principles, including voluntary participation; they are autonomous, effectively controlled, and owned by members that are located in the community (and near the projects they run). Further involving RECs would potentially help to overcome the issue of reaching tenants and homeowners as a target group. Due to their embeddedness in local social structures, RECs have a better starting position to encourage change. This might also be due to the distrust citizens have in government or for-profit businesses. However, although households that hold membership in RECs might prove easier to reach, there is the question of their motivation of being a REC member (Bauwens, 2016). A condition for the better starting position is the underlying mechanism that they are more easily persuaded because they already have strong (pro-environmental) behavioural attitudes and are exposed to subjective norms in the energy community that favour behaviour that will likely encourage home energy savings.

An overview of measures presented in Section 7 shows that RECs address home energy saving in various ways. This is done by, for example, raising awareness, providing education, and training to households and advisers, but also by providing support in audits and implementation processes. The actions of RECs have many characteristics of public policy instruments or actions of other agents. Besides the argument that involving RECs in home energy renovation might contribute to overcome the problem that tenants and homeowners are difficult to reach, RECs benefit from the closer proximity to households and the local community they belong to. The REScoop Plus project showed that overall members of REScoops were found to be committed to saving energy in terms of attitude, intention, and actual behaviour.

The results from the project show that RECs can influence households in general, and, more specifically, their members in three ways: First, via the social structure and norms that pertain to energy community membership, assuming that households obtain (or maintain) energy community membership. Second, via the active engagement of households, but in a general sense (e.g., reaching out to them by organising energy community meetings). Third, by employing dedicated actions and measures to persuade households to save energy. The present study showed that, of the reported home energy savings by the respondents, only a limited part of these (individual) energy-saving actions can, according to the respondents, be attributed to the energy community (i.e., the REScoops in the project). However, specific energy actions and dedicated measures implemented by REScoops were found to positively relate to energy savings. Specifically integrated measures (which include both antecedent and consequence strategies) can be considered fairly effective (Sifakis et al., 2020).

A major limitation of the survey-based research was that no randomised sampling was used for privacy and organisational reasons. Therefore, some of the results may be explained by the fact that only the more motivated members participated in the survey. Secondly, a (quasi-) experimental setting with independent experiments and control groups could not be created, so the effects of individual (and combinations of) interventions could not be studied in-depth.

To answer the third research question—to which extent could the potential involvement of RECs be considered a new strategy to improve the energy performance of the current housing stock?—the illustrative cases show that the specific influence of the dedicated measures is larger than the general influence of RECs on energy saving, and this influence lays in the energy community context of these dedicated measures.

There is a difference between RECs and other agents trying to reach the target group of tenants and homeowners. As presented in Section 3, RECs have certain advantages because of their social embeddedness in local communities and the trust and social acceptance they have there, as well as being a social community in itself. In taking action, particular membership is a distinguishing factor. The results from the REScoop Plus project show that all three forms of engagement between members and the energy community (i.e., membership, engagement activities, and the use of specific and dedicated measures) contribute in a positive way to the household's energy-saving intention, behaviour, and eventually energy savings. The effectiveness of the use of specific actions and dedicated measures cannot be seen without the social context of a REC. Its non-profit goals and democratic setup, in combination with the trust and acceptance they have among their members and other community members, contribute to the effectiveness of their actions and measures. Does this automatically mean that REC membership and engagement strategy are necessary conditions to better influence household energy-saving behaviour? Although some results indicate that these factors alone can already encourage household energy-saving behaviour, results of the analysis of dedicated measure implementation reveal that they can trigger and reinforce these conditions. In summary, membership, engagement activities, and specific dedicated measures appear to reinforce each other and are, arguably, jointly the most probable to trigger energy-saving behaviour among households.

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Conflict of Interests

The authors declare no conflict of interests.

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Review

Lessons From EU-Projects for Energy Renovation

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Abstract

There is an urgent need for energy renovation of the existing building stock, in order to reach the climate goals, set in Paris in 2016. To reach climate targets, it is important to considerably lower energy demand as well as switch to fossil-free heating systems. Unfortunately, renovation rates across the EU remain at a low level of 1% per year. Deep renovation, which lowers energy use with 60% or more, accounts only for 0,2% of renovations. The heating transition thus progresses much more slowly than the electricity transition. We draw on the framework of technological innovation systems, which allows comparison of different transitions. In the literature, it is argued that the configurational nature of the renovation system is one of the main reasons for the slow heating transition. The renovation system is context-bound and consists of many actors both on the demand-side and the supply-side, which leads to a fragmented market. For increasing the speed of the heating transition, it is deemed important to counter this fragmentation. We carried out a review of reports and publications of EU-funded projects on energy renovation. In many projects fragmentation in the building sector was identified as one of the main obstacles. We analyzed the deliverables of these energy renovation projects to find tried and tested solutions. One of these is the so-called one-stop-shop, which promises to improve the organization of the supply side, while also providing an appropriate and affordable solution to the customer. In the discussion we argue that the energy renovation system could be improved by increasing collaboration on the supply side and at the same time simplifying the renovation process for customers. A promising tool to make this happen is the one-stop-shop.

Keywords

energy renovation; EU-projects; heating transition; technological innovation systems

Issue

This review 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

The transition towards a more sustainable energy system will have huge ramifications for our built environment. To reach the climate goals, set in Paris in 2016, the built environment needs to considerably lower its energy demand. This is called the heating transition, which comprises two main aspects: first, reducing energy demand by building insulation and secondly, switching to fossil-free heating systems. Therefore, there is an urgent need for energy renovation of the existing building stock. Unfortunately, energy renovation rates across the EU remain at a low level of around 1% per year (BPIE, 2014; Esser et al., 2019; Sandberg et al., 2016). Moreover, the depth of the energy renovation achieved is rather shallow in most cases. Deep renovation, referring to renovation which lowers energy use with 60% or more, accounts for only 0,2% of total refurbishments (Schimschar et al., 2011). This means that both the pace and the quality or depth of energy renovation needs to increase to achieve climate goals by 2050.

There is a marked difference between the progress of the transition to renewable electricity compared to the heating transition. How could this divergence between the electricity transition and the heating transition be explained and what can we learn from the comparison between the two transitions? Some authors hypothesize that the nature of the heating transition, with a plethora of local stakeholders and the need for made-to-measure solutions for individual households and neighborhoods, causes a slower development path, compared to more centralized technologies such as large wind turbines (Wesche et al., 2019). In this respect, we examined the case of the "Energiewende" in Germany.

Germany is one of the leading countries in the energy transition (Beveridge & Kern, 2013; Hake et al., 2015), however for the building sector the Energiewende did not lead to similar progress. As Bauermann (2016, p. 237) succinctly stated, "the Energiewende which implies a revolution for the energy sector only provides little stimulus to a slowly developing residential heating market." Germany has performed a pioneering role in the promotion of renewable energy sources (RES); integration and stimulation of renewable energy have been an important part of German energy policy for over 30 years. The potential for the production of renewable energy (biomass, solar, and geothermal) is large (Bechberger & Reiche, 2004). Although Germany is heavily dependent on coal (51%) and nuclear (31%), in 2002 RES already had a share of 9% in electricity production (Bechberger & Reiche, 2004). At that time, Germany was world leader in wind energy and second in solar PV. The origin of this success lies in a combination of policy measures in place since 1990, when the Act on Supplying Electricity from Renewables or StrEG (Stromeinspeisungsgesetz) came into force (Bechberger & Reiche, 2004). This led to a breakthrough of wind energy. For solar PV the StrEG was not sufficient, here another policy measure was crucial, the Renewable Energy Sources Act or EEG (Erneuerbare Energien Gesetz) in 2000, which introduced guaranteed feed-in tariffs for 20 years (2004). The production of electricity with RES in Germany increased from 9,4% in 2011 to 40,8% in 2019 (Eurostat, 2019; Renn & Marshall, 2020). However, in these historic overviews (Bechberger & Reiche, 2004; Hake et al., 2015) it is observed that the Energiewende apparently had little effect on the heating transition. Therefore, in the next paragraphs we will dive somewhat deeper into the policies and progress of energy renovation in Germany.

Goals regarding energy use in the built environment in Germany are relatively ambitious, with 14% renewable by 2020 and climate neutrality by 2050 (Bauermann, 2016, p. 235). Germany has a renovation rate of 1%, which is comparable to other EU-countries. However, only 10% of these renovations fall in the category of "deep renovation" (Baginski & Weber, 2017; Haase & Torio, 2021; Maia et al., 2021). What policies are in place to reduce energy demand, and will the goals be met, considering the low rate of progress? The reduction of energy demand in the built environment, more specifically in dwellings, is targeted with two main approaches. The first is directed at the building itself, through insulation of walls, roof, floor and windows. The second approach is the improvement or replacement of heating systems. Apart from these building related approaches, there are policies that aim to change energy behavior. In Germany the first approach is targeted with the Energy Saving Act (1976), in which the "Wärmeschutz" supports insulation. For the second approach, heating systems, the Ordinance for Heating Systems (Heizungsanlagen-Verordnung, HeizAnlV) was put in place two years later, in 1978 (Jacob & Kannen, 2015). In 2002 these two instruments have been replaced by the Energy Savings Act (Energieeinsparverordnung, EnEV, 2002), which was updated in 2009 and 2014 (Jacob & Kannen, 2015). In 2007 the Building Retrofit Programme (CO_2-Gebäudesanierungsprogramm) was installed, which provided subsidies for homeowners to take energy saving measures when they retrofit their buildings. This program was evaluated by Clausnitzer et al. (2008), showing that 88,590 dwellings made use of this program. To stimulate the use of renewable energy for heating the Erneuerbare-Energien-Warmegesetz (EEWarmeG) was approved in 2008. Its goal was to increase RES for heating from 11% in 2011 to 14% in 2020 (Eder et al., 2021). However, most regulations are not obligatory for existing buildings.

Regarding the progress of transition in Germany's built environment we mention three scenario studies specifically investigating the heating transition in Germany. First, we refer to Bauermann (2016), who analyzes five policy scenarios, focusing on the heating market; he shows that the goals for renewable heating and for the reduction of energy demand in the existing stock will not be met with existing policies. Without regulatory and financial incentives homeowners will continue to cling to the cheaper fossil systems. Bauermann concludes that both obligations and subsidies are necessary instruments to reach the goals. Secondly, focusing on Niedersachsen, Haase and Torio (2021) examine three scenarios for the heating transition, their conclusion is that the penetration of renewable heating systems will not substantially increase, in spite of the available subsidies. They argue that this is because fossil systems, such as the combination of gas and heat pump, are also subsidized, so these remain economically more attractive. Furthermore, especially for buildings with a low energy demand, fossil systems remain the most economic option. To remedy this situation, it is important to restrict subsidies to fully renewable systems, for example combinations of heat pump and solar PV. Thirdly, the transition to near zero energy buildings (NZEBs) in Germany is investigated by Schimschar et al. (2011). Similar to the other two studies, Schimschar et al. conclude that the goals are only achievable with an intensive policy package and a high turnover of energy refurbishment, new buildings on NZEB-level, and demolition.

These modelling studies shed light on the long-term effects of policy measures. They predict the expected decisions of homeowners against the background of energy policies, prices and technologies. Homeowners are important actors in the energy renovation system. We will now look more closely at the perspective of the homeowner. Homeowners see their property as a home, a private place where they want to feel safe and comfortable (Gram-Hanssen et al., 2007). According to Baginski and Weber (2017), the decision of a homeowner to renovate should not be framed as an investment, but as a decision of a consumer. Furthermore, financial arguments are only one of the factors for owners to embark on an "renovation journey." For example, Pomianowski et al. (2019) draw on empirical research in the REFURB project and argue that economic aspects are not sufficient as a motivation of homeowners. They argue that aspects such as healthy indoor climate, architectural aesthetics, and real estate value are equally important for choosing elements to be included in renovation packages. Wilson et al. (2018) point to the complex decision-making process of homeowners and the different influences on this process, such as stage of life, meanings of home, and household dynamics. Decisions are also influenced by aesthetic considerations (Sunikka-Blank & Galvin, 2016). Esser et al. (2019, p. 50) show that personal benefits, health, environmental and financial aspects (lower costs) are all strong motivations. They find that the driver to improve the residence is the strongest.

To contribute to an explanation of the slow progress of the heating transition we draw on the framework of technological innovation systems (TISs). In this approach a technological sector or domain is viewed as a system, in which interaction between actors and the existing institutions strongly influence the speed and direction of innovation. This approach emphasizes that problems can inhibit the functioning of the system. So, the identified barriers and drivers that are often described in renovation literature (D'Oca et al., 2018) do not occur in isolation, they are part of an innovation system. The innovation systems approach has been applied to the sector of energy renovation before. In 2001, Rohracher (2001) argued to analyze sustainable building as an innovation system. For the ecological refurbishment of buildings, he concluded that there is a "deadlock of supply and demand" (Rohracher, 2001, p. 145), and further argues that a feasible approach to tackle this deadlock is by organizing a local market transformation. An application of the systems approach on the Dutch situation is provided by Faber and Hoppe (2013) and Kieft et al. (2017, 2020). Multiple systemic problems are identified that act as a blocking mechanism in the transition of NZEB-houses. Kieft et al. (2017) also reveal how systemic problems, such as the project-based approach and financial aspects, interact. For energy renovation, Kieft et al. (2020) argue that we have to differentiate between two types of logic: the steps-logic and the leaps-logic. In both types of logic, the analysis of problems and solutions differ quite widely. Kieft et al. (2020) argue that these approaches to energy renovation could be seen as representing two different innovation systems or TISs.

With the existing literature on different innovation systems, it becomes possible to compare such systems and try to explain the variations in speed and success. The slow pace of the transition to renewable energy has been explained in the context of the TIS by Negro et al. (2012). The progress of renewable energy has picked up in recent years, and thus it can now serve as a benchmark for the progress of energy efficiency in the building stock, also called the heating transition. Comparing the transition to renewable sources of electricity with the heating transition, Wesche et al. (2019) argue that the main cause of the slow heating transition is the configurational nature of its TIS. A configurational innovation system is characterized by a multitude of actors, both on the demand and the supply side, as opposed to the more compact and linear system that can be found in a generic TIS. Furthermore, Wesche et al. (2019) argue that configurational TISs are strongly embedded in the local context, which further slows down the pace of transition. Actors on the supply side tend to be locally organized, while sector organizations on a national level are not much interested in energy renovation but have other priorities. Knowledge in firms at the local level is not specialized but rather divided over many types of building projects. On the demand side, the large influence of customers is detrimental to the speed of the transition, because of the need for tailor-made solutions instead of standardization. Wesche et al. (2019) illustrate this argument by highlighting the multiplicity of components, produced by different manufacturers, offered by local installers to households. Adding to this, we should note that for a deep renovation several energy measures are necessary, all requiring specialized installers and building engineers. Moreover, households often need loans or other financial products to finance a refurbishment. To assess, calculate and combine the available measures for an energy renovation requires considerable technical knowledge of buildings, materials and installations. Therefore, access to such knowledge is crucial both for installers and homeowners.

Energy renovation is complex, innovative, and expensive, which is demonstrated by studies of the innovation system of energy renovation (Wesche et al., 2019), by long-term scenario studies (Bauermann, 2016; Haase & Torio, 2021), and by studies directly informed by homeowners' motivations (Galvin, 2012; Mlecnik et al., 2019; Wilson et al., 2015). What solutions have been developed to increase the pace of energy renovation? Several proposals to improve the local renovation system have been put forward by EU-funded projects, which we will examine in the next section.

In the remainder of the article, we will first describe our research approach (Section 2). Next, we look into the solutions for fragmentation that are proposed in EU-renovation projects (Section 3). The last part is focused on discussion and lessons learned (Section 4).

2. Research Approach: Inventory and Review of EU-Projects

In the EU-Seventh framework Programme as well as in the EU-Horizon 2020 Programme a considerable effort has been made to develop and demonstrate new solutions to energy renovation issues. We carried out an inventory of recent EU-funded renovation projects of the past 10 years. We identified 87 potentially relevant projects in several EU-databases (CORDIS, 2018). We also used snowballing to identify related projects. From this initial list we selected the projects focused on building owners and users, thus excluding projects that were primarily technical. This narrowed down the original list of projects to 38 relevant projects, which we subsequently investigated by visiting the project websites and retrieving deliverables, such as reports and information materials. The project deliverables in the sample were analyzed with Atlas.ti to find recurring themes that pertained to homeowners and energy renovation. One of the important themes emerging from this inventory is that in many projects it is considered important to counter fragmentation on the supply side as well as on the demand side. Therefore, we selected the projects that are especially relevant to this theme for further analysis and studied the reported findings. For this article, we focus on this project sample, such as REFURB, MORE-CONNECT, TripleA-reno, and Energiesprong/Transitionzero. In that sense, this article is a review of "lessons learned" in these EU-projects (Table 1).

Table 1. Overview of EU-projects that referred to one-stop-shops.

EU-project	Theme	Start	End
Abracadabra	New renovation strategy which aims at reducing the initial investment for deep renovation	2016	2019
COHERENO	Strengthen the collaboration of enterprises by eliminating barriers for collaboration, providing guidance on how to collaborate and developing services for customer segments	2013	2016
ERACOBUILD	Develop deeper, more durable cooperation and coordination between national funding bodies across Europe, to increase the quality and impact of research in the construction sector	2010	2012
iBroad	Support for "energy auditors" with ICT-based tools, including building logbook and renovation roadmap	2017	2020
Heron	Forward-looking socio-economic research on energy efficiency in EU countries; overcoming market barriers and promoting deep renovation of buildings	2015	2017
Innovate	Development and roll-out of innovative energy efficiency services	2017	2020
MORE-CONNECT	Developing prefabricated, multifunctional renovation elements and installation/building services; furthermore, the development of a one-stop-shop platform for both the customer and the production side	2014	2018
NewTrend	New participatory integrated design methodology (toolkit) to improve the energy efficiency of the existing European building stock and to improve the current renovation rate; targeted at the neighborhood level	2015	2018
ProGetOne	Combines the goal of safety upgrades to face future earthquakes in seismic zones and energy renovation	2017	2021
P2Endure	Plug-and-play product and process innovation for energy-efficient building; developed an "e-marketplace" with "plug-and-play" solutions for renovation	2016	2020
REFURB	To decrease the fragmentation of the renovation process and to bridge the gap between the supply side and demand side with dedicated renovation packages for different market segments within the residential sector	2015	2018
Stunning	Stakeholder community and knowledge sharing around renovation hub; business models for renovation, typology of one-stop-shops	2017	2019
TripleA-reno	Develop new customer-centered business models and decision support tools, designed as a gamified platform for users	2018	2021
TURNKEY RETROFIT	Develop an integrated home renovation service, designed as a homeowner-oriented renovation journey, aiming to transform the complex and fragmented renovation process into a simple, straightforward and attractive process for the homeowner	2019	2021

3. Lessons From EU-Projects: Solutions for Fragmentation

In our project sample, the urge to counter fragmentation was expressed in many projects. Several approaches are developed and tested. A common proposition is the formation of a "one-stop-shop for renovation." In the development of such a one-stop-shop, cooperation on the local level and knowledge exchange between stakeholders on the supply side is stimulated. On the other hand, a one-stop-shop also aims to support homeowners with decision making in the renovation process.

The one-stop-shop for renovation is a concept that was first investigated in the EU by ERACOBUILD, an EU-funded project that ran from 2010 to 2012 (ERACOBUILD, 2012). In this project it was argued that:

> Existing barriers include the fragmentation of the renovation process, which is split among many SMEs, each doing a fraction of the renovation work. Moreover, homeowners do not have a structured way to obtain all the necessary information for decisions on renovation solutions, contacts with building companies, quality assurance, and financing opportunities. (Haavik et al., 2012, p. 5)

ERACOBUILD aimed to learn from demonstration projects in Norway, Belgium, and the Netherlands, and to pave the way for new one-stop-shops (Mlecnik et al., 2012). Importantly, ERACOBUILD also published guidelines to help SMEs to develop a business model for a one-stop-shop for renovation (Haavik et al., 2012).

A second EU-funded project that addressed the fragmentation of the renovation process is REFURB, which aimed to help the homeowner with navigating the energy renovation journey (European Commission, 2015; Pomianowski et al., 2019). In this project both the supply as well as the demand side of the renovation market was investigated, including a SWOT-analysis of seven one-stop-shops in EU-countries (D3.3/D3.4). An important barrier for homeowners is the difficulty to obtain the necessary information for decisions on renovation solutions. Interestingly, they found that the non-technological solutions, such as new ways of financing, new approaches to organize the supply side, quality assurance and one-stop-shop solutions, proved to be more important than the technological solutions to seduce homeowners to renovate to NZEB-level (Cuypers & Rathje, 2016, p. 29). The project aimed to bring together the supply side (building construction sector) and demand side (homeowners) by developing a "compelling offer": a renovation package based on a match between available technologies and homeowners' concerns. For example, in the Better Home program in Denmark, homeowners first got a free energy review to assess what needed to be done and then were brought into contact with qualified craftsmen who could carry out the renovation. Better Home also worked together with local banks to secure competitive loans to help homeowners to finance renovation projects. REFURB's partner Leiedal (Belgium) developed an online tool, My Energy Compass, which can inspire development of tools in other regions in Europe. This tool gives information and nudges the homeowner to proceed in the renovation journey (Antonov & Pomianowski, 2017).

Thirdly, TURNKEY RETROFIT is an EU-funded project that emphasizes that the energy renovation market in the EU is potentially very large, keeping in mind the high ambitions on EU-level for renovating existing building stock (European Commission, 2019). The project identifies the fragmentation of this energy renovation market as one of the main problems, pointing to both the supplier and customer's side. Integrated renovation services are seen as one of the solutions for fragmentation. On the basis of an evaluation of nine integrated services the key elements for the TURNKEY RETROFIT integrated service/one-stop-shop are outlined. A homeowner-oriented renovation journey was developed, which offered tailormade solutions and guides the homeowner through the whole renovation process. This also included a technical offer, help with finding financial support, but went even further and provided on-site coordination of works and quality assurance. Furthermore, TURNKEY RETROFIT also developed a digital platform for homeowners (D'Oca et al., 2019; Desmaris et al., 2019; Volt et al., 2019).

Fourth, we find the Energiesprong campaign in the Netherlands (Energiesprong, 2021), which aimed to use the social housing sector as a catalyst for kickstart net-zero energy refurbishment markets. The related, EU-funded project Transition Zero aimed to build on the success of Energiesprong and advance its implementation to the UK and France. Supported by Energiesprong, more than 12,000 dwellings were built or renovated to ZEB-standards. However, for renovation, the aim to stimulate zero energy renovations in the private market largely failed, presumably because of rising prices, as is shown by the low numbers of zero energy renovations in owner-occupied dwellings (Bekkema & Opstelten, 2019). Furthermore, the expected financial benefits of scale and experience did not materialize for the same reasons, which caused social housing corporations to retract from zero energy renovations (Van Goor & Brink, 2020).

Fifth, the EU-funded project MORE-CONNECT (MORE-CONNECT, 2018) sought solutions in the combination of prefabricated, multifunctional renovation elements and the provision of renovation services. To that end, MORE-CONNECT developed a "one-stop-shop," where the end-user will deal with only one party, which is responsible for the total renovation. Hindrance will be reduced to the minimum by limiting renovation time to five days, while occupants can stay at home during the renovation process.

Lastly, we briefly refer to TripleA-reno (TripleA-reno, 2018), which refers to Affordable, Acceptable, and Attractive renovation, with users in the centre. In this project, a gamified platform was developed to provide users of deep renovation projects with attractive, understandable, and personalized information (D'Oca et al., 2019). Another relevant EU-funded project in this respect is COHERENO, which ran from 2013 to 2016 (see, e.g., Mlecnik et al., 2012, 2019; Straub, 2016).

Summarizing, the concept of the one-stop-shop is promoted as an appropriate solution for defragmentation in the renovation market. Such "shops" provide easy access to information and building analysis to customers, they connect stakeholders from different backgrounds, from building physics to financial assistance. The proposed shops do not necessarily contain all these functions, for example MORE-CONNECT is focused on prefabricated building elements and building modeling, while REFURB proposes a combination of renovation measures with financial solutions. Other approaches contain elements of gaming, such as TripleA-reno. Lessons learned from existing one-stop-shops are described in several projects (Haavik et al., 2012; Mlecnik et al., 2012, 2019).

4. Discussion

The diagnosis of the slowness of the heating transition by Wesche et al. (2019) suggests that stronger organization and cooperation of the supply sector is needed to make progress. Moreover, the demand side also needs to be involved, the cooperation of the primary decision maker, the homeowner, is necessary. The "one-stop-shop" for renovation is one of the solutions that is proposed to bring together stakeholders from the building sector with homeowners. In the literature, it is recognized that one-stop-shops can reduce transaction costs of energy renovations (Ebrahimigharehbaghi et al., 2019). In our inventory, we identified several EU-projects that have investigated and demonstrated such a "one-stop-shop," in which stakeholders worked together to formulate a "convincing offer" for homeowners.

However, the homeowner often needs to search for information about specific components or technical approaches, because not all installers have up-to-date technical knowledge to advise on new or innovative solutions. Moreover, there are also financial, regulatory, or other elements relevant to the TIS. For example, homeowners often need a loan to cover the considerable costs of the renovation. In many EU-countries it proves difficult to get such a loan, because banks have uncertainties about the energy performance or the value of the renovated property (Lugies, 2021).

The heating transition is highly context-based, as it depends on local suppliers and individual customers. According to Wesche et al. (2019), this situation contributes to the slow pace of the heating transition. Other factors are a lack of knowledge, lack of available finance for homeowners, and a low level of regulation. Together, the fragmentation of the market, lack of sufficient information, and absence of guarantees are important factors that keep customers from investing in deep energy renovation.

The heating transition is dependent on two main parts: reducing demand and renewable supply. Reducing energy demand through energy renovation of existing buildings progresses very slowly, as previously stated in the Introduction (BPIE, 2014). The same goes for the transition towards renewable heating systems (Bauermann, 2016). Compared to the financial incentives for renewable electricity, policies to stimulate fossil-free heating systems stay behind (Haase & Torio, 2021). On the basis of these studies, it is expected that without proper financial and regulatory incentives for renewable heating systems the dominance of fossil-based systems is likely to continue in the coming decades (Bauermann, 2016; Haase & Torio, 2021). Policies for sustainable heating could be improved by learning from the simple, long-term financial remuneration that was provided for individual PV-systems in Germany.

Furthermore, the analysis of the renovation system (Wesche et al., 2019) suggests that measures to improve cooperation and communication between stakeholders in the renovation system on local as well as national levels could increase the energy renovation rate. Several EU-projects have demonstrated that one-stop-shops are a viable solution to remedy the fragmentation of the supply-side and provide clear and accessible information to customers.

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Conflict of Interests

The author declares no conflict of interests.

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