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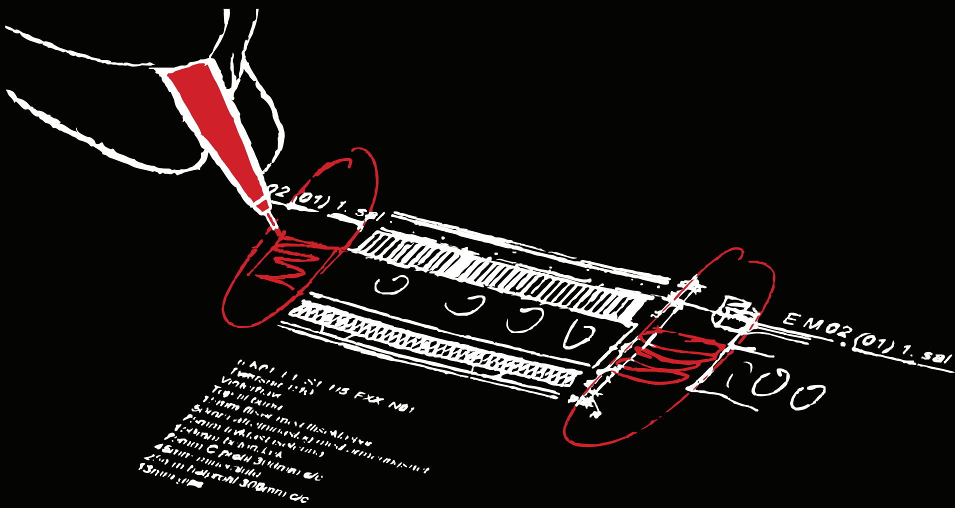
The Making of an ENERGY RENOVATION



Knowing & Acting on Energy-Saving Features through Design Processes

By

Daniel Pihl

BREAKING NEW GROUND
AALBORG UNIVERSITY

THE MAKING OF AN ENERGY RENOVATION

KNOWING AND ACTING ON ENERGY-SAVING FEATURES THROUGH DESIGN PROCESSES

by

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Daniel Pihl has a Bachelor of Arts in Architectural Technology and Construction Management at Copenhagen School of Design and Technology. His bachelor's degree as a trained construction architect gives him insight into the practical making of construction projects and building designs. Daniel holds a Master of Science in Technology (Construction Management and Informatics) from Aalborg University Copenhagen. His master thesis investigated how building designers used a software application to manage rooms and equipment during the design of a major hospital construction project. Drawing on actor-network theory, the master thesis focused on the emergence of heterogeneous actors and their attempts to mobilise other actors, as well as the redistribution of competences in the network. He finished his master's thesis in 2014 and shortly after became employed as a research assistant at the Danish Building Research Institute for a year. Daniel became a PhD student at the Department of Development and Planning, Aalborg University Copenhagen, in 2015 where he has been part of the Sustainable Design and Transition Research Group whose research revolves around the socio-technical, organisational and economic processes related to sustainable transition.

SUMMARY

Climate changes challenge the world, and recent climate changes show widespread effects on societies and the environment (IPPC, 2014). Human activities affect the climate through the emission of greenhouse gases, and around the globe, politicians, governments and organisations commit themselves to reducing greenhouse gas emissions in hope of mitigating the damages associated with climate changes. The building industry plays a vital role in the reduction of emissions, since the building industry accounts for 9 % of the global greenhouse gas emissions and 40 % of the global energy use (Yeatts, Auden, Cooksey, & Chen, 2017). The existing building stock represents a significant potential for energy reduction, and hence reduction of greenhouse gases, since most of the existing building stock will remain over the coming decades and a large amount of existing buildings are built before current energy regulations (Fyhn, Søraa, & Solli, 2019). To meet the challenges of climate changes, reduction of energy consumption in existing buildings is crucial and energy renovations are necessary means.

Most of the scientific literature on energy renovations focuses on the technical measures to reduce energy consumption and the economic benefits associated with particular renovation measures. Although renovation measures to reduce energy consumption is decided during the design of energy renovations, researchers tend to 'black box' (Latour, 1987) such processes into a series of steps, decisions or phases (e.g. Mortensen et al., 2017). The large focus on technical and economic aspects of energy renovations overlook the social and material relations that constitute the 'making of energy renovations.' This thesis draws on science and technology studies, and especially the sociology of associations which is also called actor-network theory, and focuses on the practical, everyday design practices in which energy-saving measures emerge out of interactions between designers and material objects. By opening up the black box of designing energy renovations, this study examines how the designers involved in one specific energy renovation project make energy-saving design features knowable and actionable through social and material design processes.

Most of the research on energy and buildings draws on the 'sociology of consumption' movement where researchers mostly find inspiration in practice theory (e.g. Shove 2004). In their study of renovation practices, the researchers mainly focus on households, or relations between households and professionals, or the design and use of energy-saving technologies. Within energy and buildings literature, little attention has been paid to how designers handle energy-saving measures through their design processes. In an

attempt to understand design processes, this thesis draws on literature on design thinking where researchers emphasise the practices of designing, the mutual making of design problems and solutions, and the importance of relations between designers and material objects. Furthermore, this thesis finds inspiration in the literature on building design processes, where researchers mainly draw on the sociology of associations and emphasise the emergence of construction phenomena and the importance of material objects in making buildings knowable, actionable, and real. This thesis finds inspiration in the three bodies of work concerning energy and buildings, design practices, and building design processes in order to study the making of an energy renovation.

The research objective of this thesis is to study how designers make energy-saving design features knowable and actionable, and for this purpose, drawing on the sociology of associations is useful since this research tradition arises from a research interest in how scientists come to know the things they know (Latour & Woolgar, 1979). The sociology of associations provides a vocabulary that focus on processes of translation, mobilisation, and inscription for the analysis of knowledge production and technological development. In the pursuit of studying how designers make energy-saving design features knowable and actionable, ethnographic research methods have been conducted, including video recordings of design meetings, interviews with the involved designers, and review of project documents and drawings. The analysis focuses on five controversial design issues concerning energy performance that emerge from the practices of the designers. The five issues concern the choice of ventilation system with heat recovery, the specification of energy requirements, the thermal insulation to prevent thermal bridges in the facades, the thermal insulation of the basements, and the thermal insulation to prevent floor heating in heating downwards.

This study focuses on one particular energy renovation project which the research participants call 'ambitious' and 'comprehensive.' The energy renovation project involves four multi-family apartment buildings built in the 1960s and constructed in prefabricated concrete elements. The buildings are rented out as social housing which means that three organizations share the role of the building client, namely an administrator organisation, a housing association, and a housing section. This study focuses on the design of the energy renovation projects and observes the everyday practices of designers at one company responsible for the delivery of the detailed project design to the building client. The company is an engineering consultancy company with employees trained as architects, engineers, and construction architects. Fieldwork was carried out across 11 months from August 2015 to June 2016 which make up the time where the designers were working on the design of the energy renovation project.

The findings of this study show how the designers make energy-saving design features knowable and actionable through the negotiation of interests and the use of material objects. The designers negotiate the definition of the design features and attempt to convince each other about following specific design suggestions. The making of energy-saving designs involve competing concerns, since interests in energy savings compete against other building design concerns, such as the stability of the buildings or the architectural design concept. Energy-saving design features have to stand the test through trials of strength as translations of interests clash and create negotiations. Previous documents become spokespersons for the initial ambitions of reducing energy consumption and new documents are treated as obligatory passage points to enhance the interests of specific designers. When energy-saving design features materialise, they stabilise parts of the design and simultaneously raise questions concerning other parts of the design. The designers use material objects to explore design features, but also to mobilise others in joining specific programs of action. Instead of presenting the design process as straightforward, the findings show how the design process involves hesitation to specify particular design features, betrayal of important areas to insulate, and needs to re-make already-agreed-upon design features.

Based on the findings, this study discusses the 'everydayness' of designing energy renovations. It is through their everyday practices that the designers translate abstract, context-independent ambitions of energy savings into specific design details. While doing so, the designers experience a number of challenges and conflicts that risk diminishing the energy-saving ambitions. Because energy renovations involve competing concerns, the designers engage in persuasive processes where they attempt to convince each other to follow specific design suggestions. Material objects scaffold the persuasive processes by providing stability to the negotiation of interests. The designers engage in learning processes, where they discover design features and test design suggestions through interaction with material objects. The material objects enable the designers to grasp some design aspects, while they hide other design aspects by keeping them unknown to the designers. The designers engage in processes of 'fixing' and 'unfixing' design features as they interact with material objects. The materialisation of design features enables them to become 'locked,' that is, considered as 'agreed-upon' and 'given' by the designers. However, the stabilisation is never complete or indefinitely. Design features that had been considered 'fixed' may become open once more for the scrutiny of the designers. In this way, the designers move between sets of 'fixed' and 'unfixed' design features.

This thesis illustrates the importance of studying the everyday practices of designers as they design energy renovations since if research does not draw attention to the everyday challenges and conflicts happening during the design of energy renovations, then ambitions concerning reductions in energy consumption are likely to fall short. Energy savings are often assumed to be well-known, well-defined, context-independent, and a matter of technique (Guy & Shove 2000). However, this study documents that energy savings are not given and designers make energy-saving measures knowable and actionable through design practices. If researchers treat the design of energy-saving measures as 'black-boxed' entities (Latour 1987), then scholars risk overlooking the possible changes energy-saving measures go through as they are translated from abstract energy requirements into specific design suggestions.

RESUMÉ

Klimaforandringer udfordrer verden, og de seneste klimaændringer har omfattende eftervirkninger på samfund og miljøet (IPPC, 2014). Menneskelige aktiviteter påvirker klimaet gennem emission af drivhusgasser, og rundt om i verden forpligter politikere, regeringer og organisationer sig til at reducer drivhusgasserne i håb om at afværge skaderne forbundet med klimaforandringerne. Byggeindustrien spiller en afgørende rolle i reduktionen af drivhusgasserne, da byggeindustrien står for 9% af de globale drivhusgasemissioner og 40% af det globale energiforbrug (Yeatts, Auden, Cooksey & Chen, 2017). Den eksisterende bygningsmasse udgør et betydeligt potentiale for energibesparelse og dermed reduktion af drivhusgasser, da det meste af den eksisterende bygningsmasse vil forsat være her i de kommende årtier, og mange eksisterende bygninger er bygget før de nuværende energibestemmelser (Fyhn, Søraa, & Solli, 2019). For at imødegå udfordringerne ved klimaforandringerne er reduktion af energiforbruget i eksisterende bygninger afgørende, og energirenoveringer er en nødvendig indsats.

Det meste af den videnskabelige litteratur om energirenoveringer fokuserer på de tekniske foranstaltninger til reduktion af energiforbruget og de økonomiske fordele forbundet med særlige renoveringstiltag. Selvom renoveringstiltag møntet på reduktion af energiforbrug bliver besluttet under design af energirenoveringer, har forskere en tendens til at "black boxe" (Latour, 1987) disse processer i en række trin, beslutninger eller faser (fx Mortensen et al., 2017). Det store fokus på tekniske og økonomiske aspekter af energirenoveringer overser de sociale og materielle relationer, der udgør "produktionen af energirenoveringer." Denne afhandling tager udgangspunkt i 'science and technology studies,' og især aktør-netværksteori, og fokuserer på de praktiske, designpraksisser som designere udfører på daglig basis, hvor energibesparende tiltag opstår fra interaktioner mellem designere og materielle objekter. Ved at åbne den 'sorte boks' til design af energirenoveringer, undersøger denne afhandling hvordan designerne involveret i et specifikt energirenoveringsprojekt gør energibesparende designdetaljer 'erkendelige' (knowable) og 'handlingsrettet' (actionable) gennem sociale og materielle designprocesser.

Det meste af forskningen indenfor energi og bygninger trækker på 'the sociology of consumption,' hvor forskere hovedsagelig finder inspiration i praksisteori (fx Shove 2004). I deres undersøgelser af renoveringspraksis fokuserer forskerne primært på husholdninger, eller forholdet mellem husholdninger og professionelle, eller design og anvendelse af energibesparende teknologier. Inden for energi- og byggelitteratur er der blevet lagt lidt vægt på, hvordan designere håndterer energibesparende tiltag gennem deres designprocesser. I et forsøg på at forstå designprocesser bygger denne afhandling

på litteratur om designtænkning, hvor forskere lægger vægt på designpraksisser, gensidig produktion af designproblemer og løsninger, samt betydningen af relationer mellem designere og materielle objekter. Desuden finder denne afhandling inspiration i litteraturen om designprocesser indenfor byggeri, hvor forskere hovedsagelig trækker på aktør-netværksteori og fremhæver produktionen af byggefænomener og vigtigheden af materielle objekter i at gøre bygninger erkendelige, handlingsrettet, og 'virkelige.' Denne afhandling finder inspiration i de tre grupper af forskning vedrørende energi og bygninger, designpraksis og designprocesser indenfor byggeri for at studere designet af en energirenovering.

Forskningsformålet med denne afhandling er at undersøge, hvordan designere gør energibesparende designdetaljer erkendelige og handlingsrettet, og i den forbindelse er det muligt at trække på aktør-netværksteori, da denne forskningstradition stammer fra en forskningsinteresse i, hvordan forskere kommer til at vide de ting, de ved (Latour & Woolgar, 1979). Aktør-netværksteori giver et ordforråd, der fokuserer på processer såsom 'translation,' 'mobilisation' og 'inscription' til analyse af videnproduktion og teknologisk udvikling. I efterstræbelsen på at studere, hvordan designere gør energibesparende designdetaljer erkendelige og handlingsrettet, er der udført etnografiske forsknings-metoder, herunder videooptagelser af designmøder, interviews med de involverede designere og gennemgang af projektdokumenter og tegninger. Analysen fokuserer på fem kontroversielle designproblemer vedrørende energibesparelser, der fremkommer af designernes praksis. De fem problemer vedrører valget af ventilationssystem med varmegenvinding, specifikationen af energikrav, termisk isolering for at forhindre kuldebroer i facaderne, isolering af kældrene, og isoleringen for at forhindre gulvvarme-systemer i at varme nedad.

Denne undersøgelse fokuserer på et specifikt energirenoveringsprojekt, som forskningsdeltagerne kalder et 'ambitiøst' og 'omfattende' projekt. Energirenoverings-projektet omfatter fire etageboliger bygget i 1960'erne og bygget i præ-fabrikerede betonelementer. Bygningerne udlejes som almene boliger, hvilket betyder, at tre organisationer deler bygherrerollen, nemlig en administratororganisation, en boligforening og en boligafdeling. Denne undersøgelse fokuserer på udformningen af energirenoveringsprojektet og observerer den daglige praksis udført af designere hos et specifikt firma, der er ansvarlig for leveringen af det detaljerede hovedprojekt til bygherren. Virksomheden er et ingeniørkonsulentfirma med medarbejdere, der er uddannet som arkitekter, ingeniører og bygningskonstruktører. Feltarbejde blev udført i løbet af 11 måneder fra august 2015 til juni 2016, hvilket udgør den tid, hvor designerne arbejdede på udformningen af energirenoveringsprojektet.

Resultaterne af denne undersøgelse viser, hvordan designerne gør energibesparende designdetaljer erkendelige og handlingsrettet gennem interesseforhandlinger og brug af materielle objekter. Designerne forhandler definitionen af designdetaljerne og forsøger at overbevise hinanden om at følge specifikke designforslag. Fremstillingen af energibesparende design indebærer konkurrerende interesser, da interesser i energibesparelser konkurrerer imod andre bygningsproblemer, såsom bygningernes stabilitet eller det arkitektoniske designkoncept. Energibesparende designdetaljer skal afprøves gennem 'trails of strength,' da 'translation of interests' kolliderer og skaber forhandlinger. Tidligere dokumenter bliver 'spokespersons' for de indledende ambitioner om at reducere energiforbruget, og nye dokumenter behandles som 'obligatory passage points' for at øge de specifikke designers interesser. Når energibesparende designdetaljer bliver materialiseret, stabiliserer de dele af designet og rejser samtidig spørgsmål vedrørende andre dele af designet. Designerne bruger materielle objekter til at udforske designdetaljer, men også til at mobilisere andre ved at tilslutte sig specifikke 'programs of action.' I stedet for at præsentere designprocessen som enkel og ligefrem viser resultaterne, hvordan designprocessen involverer tøven med at specificere bestemte designdetaljer, 'forræderi' hvor vigtige isoleringsområder bliver forsømt og et behov for at genskabe allerede aftalte designdetaljer.

Baseret på resultaterne diskuterer denne undersøgelse 'the everydayness' af at designe energirenoveringer. Det er gennem deres daglige praksis, at designerne oversætter abstrakte, kontekstuafhængige ambitioner om energibesparelser til specifikke designdetaljer. Samtidig oplever designerne en række udfordringer og konflikter, som risikerer at mindske de energibesparende ambitioner. Fordi energirenoveringer indebærer konkurrerende interesser, involverer designerne sig i 'persuasive processes,' hvor de forsøger at overbevise hinanden om at følge specifikke designforslag. Materielle genstande støtter 'persuasive processes' ved at give stabilitet til forhandling af interesser. Designerne engagerer sig i læringsprocesser, hvor de opdager designdetaljer og tester designforslag gennem interaktion med materielle objekter. De materielle objekter sætter designerne i stand til at forstå nogle designaspekter, mens de skjuler andre designaspekter ved at holde dem ukendte overfor designerne. Designerne engagerer sig i processer med 'fixing' og 'unfixing' designdetaljer, mens de interagerer med materielle objekter. Materialiseringen af designdetaljer gør det muligt for dem at blive 'låst', der betragtes som 'aftalte' og 'givet' af designerne. Imidlertid er stabiliseringen aldrig fuldstændig eller på ubestemt tid. Designdetaljer, der var blevet betragtet som 'fastlåste', kan blive åbne endnu en gang for at undersøge designdetaljerne en gang til. På denne måde bevæger designerne sig mellem sæt af 'faste' og 'løse' designdetaljer.

Denne afhandling illustrerer betydningen af at studere den dagligdagspraksis som designere indgår i når de designer energirenoveringer, fordi hvis forskning ikke bliver opmærksom på de daglige udfordringer og konflikter, der opstår under udformningen af energirenoveringer, vil ambitioner om reduktion af energiforbrug sandsynligvis ikke være tilstrækkelig. Energibesparelser antages ofte for at være velkendte, veldefinerede, kontekstuafhængige og et spørgsmål om teknik (Guy & Shove 2000). Denne undersøgelse dokumenterer imidlertid, at energibesparelser ikke er givet på forhånd, og designere gør energibesparende tiltag erkendelige og handlingsrettet gennem designpraksis. Hvis forskere behandler design af energibesparende foranstaltninger som "black boxed" (Latour 1987), så risikerer forskere ikke at se de mulige ændringer, energibesparende foranstaltninger går igennem, idet de oversættes fra abstrakte energikrav til specifikke designforslag.

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CHAPTER 1 Introduction

Introduction

ENERGY SAVINGS IN EXISTING BUILDINGS

Climate changes challenge the world, and according to the Intergovernmental Panel on Climate Change (IPCC), recent climate changes show widespread effects on societies and the environment (2014, p. 2). Human activities affect the climate through the emission of greenhouse gases, and anthropogenic emissions have never been higher than they are today (*ibid.*). Around the globe, commitments are made by politicians, governments, and organisations to reduce greenhouse gas emissions in the hope of mitigating the damages associated with climate changes. The largest source of greenhouse gas emissions is the burning of fossil fuels for energy to be used for heating, electricity, transport and industry and it takes up two-thirds of the global amount of emissions (European Environment Agency, 2017, p. 5). The reduction of energy use is paramount in the challenge which climate changes pose. The building industry is vital for the reduction of energy use, since the energy used to construct, operate and demolish buildings account for 40 % of the global energy use and 9 % of the global greenhouse gas emissions (Yeatts, Auden, Cooksey, & Chen, 2017). In Denmark, buildings consume 41 % of the total end-use energy demand (Mathiesen et al., 2016, p. 21). To meet the challenges of climate changes, reduction of energy consumption in buildings is crucial.

The European Parliament has issued directives to address environmental challenges and promote more energy efficiency in the European building sector. The member states are given incentives to reduce the operational energy use in buildings through the introduction of energy certification of buildings and minimum energy requirements for new buildings as well as the promotion of energy renovation of existing buildings (Asdrubali et al., 2019, p. 461). The European Directive 2010/31/EU requires all new buildings in member states to be nearly zero-energy buildings by 2020 and new public buildings by 2018 (European Parliament, 2010). Moreover, the European Directive 2012/27/UE requires member states to establish a strategy for the renovation of the existing building stock where public bodies should lead the way by renovating 3 % of heated floor area of public buildings by 2014 (European Parliament, 2012). Based on the directives, the Danish Government has stated that they intensify their ambitions for energy savings over the years and aims at making Denmark independent of fossil fuels by 2050 (Knudsen & Jensen, 2015, p. 7). According to the Energy Efficiency Watch (2016), Denmark has one of the most ambitious and strictest minimum energy performance standards for new buildings among comparable countries in the European

Union. In 2012, the Danish Energy Agency proclaimed that the energy requirements for new buildings in Denmark had been tightened considerably over the past 25 years (Danish Energy Agency, 2012, p. 31). However, the strict energy efficiency requirements in the Danish building regulations focus mostly on new buildings.

Tightening energy regulation for new buildings is important, but as described by the International Energy Agency (2013), actions cannot be limited to new buildings only. More than half of the current global building stock is expected to remain in 2050, and since buildings typically last for more than 100 years (*ibid.*, p. 25), there is a significant potential in renovating the existing building stock. Replacements of existing buildings are rare, and estimates from now and to 2050 suggest that only 0.25 % of existing buildings will be demolished per year which makes new buildings a supplement to the existing stock rather than a 'phasing out' of existing buildings (Mathiesen et al., 2016, p. 24). Most of the existing building stock will still be standing in the coming decades, and since construction of most of the stock happened before current energy regulations, the existing building stock represents a tremendous potential for energy reductions (Fyhn, Søraa, & Solli, 2019, p. 134). However, renovation of the existing building stock is happening at a low speed, and according to the Buildings Performance Institute Europe (2018), the current rates of renovation needs to be increased with a factor 2-3 to achieve necessary changes in energy use. In Denmark, the existing building stock holds great potential to achieve space heating savings as the performance of older buildings, and especially the ones constructed before 1970, is significantly lower than new buildings (Mathiesen et al., 2016, p. 24). Besides the potential of energy savings by renovating existing buildings, renovations in most cases also lead to improved indoor climate, enhanced comfort and living conditions for the people living in the buildings (the State of Green, 2018, p. 3).

The enormous potential in energy savings that renovations offer has drawn the attention of researchers towards estimates of possible effects on energy consumption when implementing specific renovation measures. Based on case studies of particular buildings, researchers estimate energy savings before and after a renovation to present the outcomes of specific renovation initiatives (e.g. La Fleur, Moshfegh, & Rohdin, 2017; Mörmann & Lützkendorf, 2016). The purpose of such studies is to illustrate how specific renovation measures impact energy performance, as well as other aspects such as indoor environment, and in this way support stakeholders in making 'effective' energy saving choices and 'cost-effective' renovation investments. While these studies focus on technical improvements of buildings or economic advantages regarding energy renovation, researchers have also drawn attention to how the use of buildings impacts the energy consumed in the buildings. Energy consumption is not only a product of technical features of the building or the energy system, but the practices of occupants also influence it (e.g. Fawcett & Killip, 2014; Gram-Hanssen, 2014; Guerra-Santin & Silvester, 2016; Maller, Horne, & Dalton, 2012).

In the pursuit of studying the effects of energy renovations, researchers have identified a ‘performance gap’ between expected, theoretical, calculated energy savings and actual, measured energy savings (e.g. de Wilde, 2014; Gram-Hanssen & Georg, 2018; Majcen, Itard, & Visscher, 2016; Sunikka-Blank & Galvin, 2012; van den Brom, Meijer, & Visscher, 2018). The rationale for why the performance gap exists is different in the studies. By extending a point made by Topouzi, Owen & Killip (2017), the debate about performance gaps revolves around three themes: 1) the use and accuracy of building energy models in predicting energy savings, 2) the influence of occupant behaviour in estimations of both expected and actual energy consumption, and 3) the technical malfunction of renovation measures according to how their design and construction. Discussions about the effects of energy renovations are imperative, however, the three themes only shed light on some of the topics and research areas which influence the energy performance of buildings concerning renovation. With a few notable exceptions (e.g. Janda & Killip, 2013; Janda & Parag, 2013), relatively little attention has been given to how issues associated with designing, constructing, introducing or installing new technologies in buildings are handled by professional actors, even though these practices may have profound effects on the energy performance of buildings. The effects of energy renovations depend on decisions made during the design and planning of the renovations (Konstantinou & Knaack, 2013; Palm & Reindl, 2018). The lack of attention calls for more research on the processes of designing and constructing energy renovations and how technologies are introduced and installed in buildings. This study contributes to such an endeavour by exploring the design of an energy renovation.

THE CORNERSTONES IN ENERGY RENOVATION RESEARCH

Much of the scientific literature on energy renovations focuses primarily on the economic benefits associated with renovation initiatives that reduce energy consumption in buildings. At least this is what Friege & Chappin (2014) find, based on a literature review of 449 scientific articles and conference proceedings as well as their references. Nevertheless, Friege & Chappin suggest that homeowners decide to carry out energy renovations based on both economic goals and non-economic goals (*ibid.*, p. 205). Among the non-economic goals, they mention lower energy bills, improved comfort, and reduced environmental impact of the homeowners. According to De Boeck, Verbeke, Audenaert & Mesmaeker (2015), much of the scientific literature on energy efficiency in residential buildings is dedicated to identifying different research methods to develop solutions that can 'optimise' energy efficiency in buildings (p. 972). Together with economic evaluations, studies of energy renovations present 'cost-optimal' renovation initiatives to achieve energy-efficient buildings (e.g. Ferreira, Almeida, Rodrigues, & Silva, 2014).

Researchers focus on types of technical interventions to buildings, how much energy savings such interventions can provide, and what the costs of the interventions might become if homeowners decide to follow similar procedures. For example, Kuusk & Kalamees (2015) provide estimations of current energy consumption of specific buildings and describe interventions, which would lead to a 'deep renovation' of the buildings, and then discuss the financial consequences of these renovations. The study by Kuusk & Kalamees is just one of many, which presents possible renovation initiatives, their energy-saving potential, and related costs – all of it based on case studies of particular buildings and calculations made by the authors. Moreover, De Boeck et al. (2015) state that many of these kinds of studies focus on interventions such as changing windows or improving the thermal insulation of the envelope. However, studies of changes in and installation of HVAC systems have recently gained ground (p. 972). These results highlight how energy renovation research has hitherto focussed mainly on issues on technical interventions, economic benefits, and cost-optimal evaluations of possible renovation initiatives.

Furthermore, many studies of energy renovation projects mostly adopt a linear description of how projects develop over time. Thuvander, Femenías, Mjörnell & Meiling (2012) describe a series of 'significant decisions' for the preliminary investigation phase of energy renovation projects. The decisions are illustrated as a linear progression from 'needs for renovation' over 'renovation works' to 'user phase' (see figure 1.1). Similarly, Ma, Cooper, Daly & Ledo (2012) illustrate 'important steps' practitioners can take during energy renovations. For each step, a subsequent step follows with the occasional input from energy performance assessment methods and other decision support tools (*ibid.*, p. 892). Moreover, Ma et al. (2012) describe energy renovations as consisting of five phases and where project participants should be aware of specific topics in each phase.

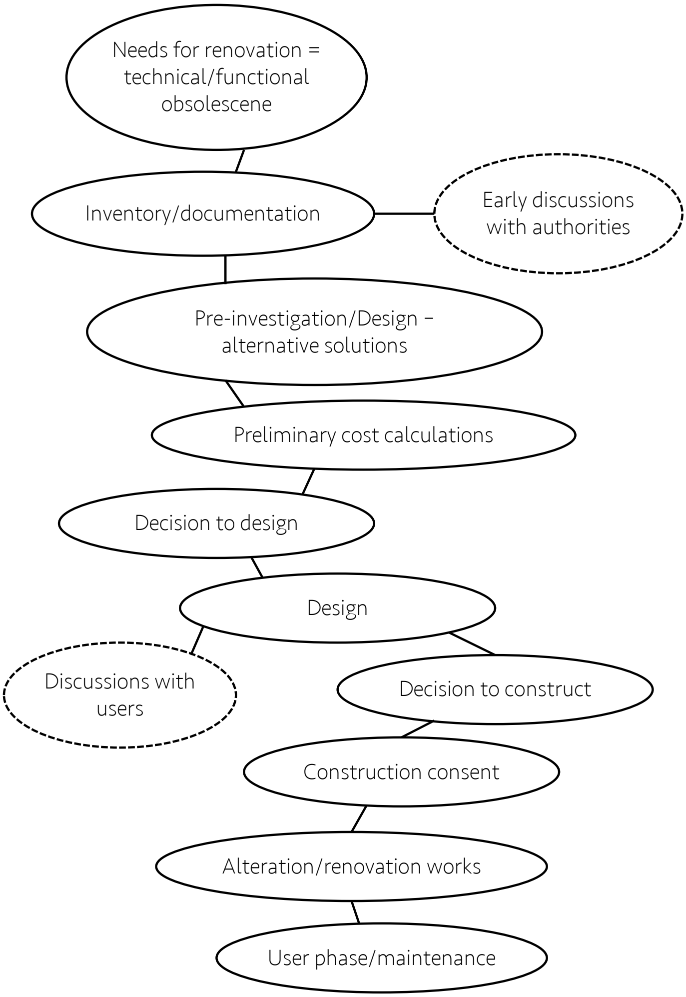

Figure 1.1: The figure shows an illustration of the renovation process presented in Thuvander, Femenías, Mjörnell & Meiling (2012, p. 1193). The illustration shows a linear movement between a series of decisions and processes.

Nielsen, Jensen, Larsen & Nissen (2016) define a set of 'steps' for the pre-design phase and the design phase. They emphasise how the phases may become iterative, and 'sub-iterations' within the phases may take place. However, their illustration of these steps remains linear, even though it includes a feedback loop from renovation activities and back to the beginning of the model indicating the start of a new renovation project (*ibid.*, p. 166). Although these three models vary concerning content and focus, they all share the same assumption that these models can be used on any building with perhaps only a few modifications (Ma et al., 2012, p. 892). A publication by the Danish Building Research Institute builds on a similar line of reasoning (Mortensen et al., 2017). The Danish Building Research Institute provides professionals in the Danish building sector with instructions on how to plan, build, and maintain buildings properly and in this publication, energy renovation projects (in large buildings) are divided into five phases, in which particular stakeholder constellations and 'key focus areas' for the potential project success figure prominently (Mortensen et al., 2017). This publication, along with the three articles mentioned above, is illustrative of how researchers consider energy renovation projects to be proceeding linearly, involving a series of steps, decisions, or tasks which need to be fulfilled or reflected upon a particular point in time in order to ensure a successful energy renovation.

In keeping with this vein of literature, there is also a large number of studies reporting on the development of decision support tools for selecting renovation measures to reduce energy consumption (e.g. Fouchal et al., 2017). These studies aim at providing information about various renovation alternatives, rank them according to costs and energy-efficiency, and in this way, guide decision-makers during the design of energy renovations. Lee et al. (2015) describe these as 'methods to identify the most cost-effective energy savings for individual or combinations of retrofit measures' (p. 1087). They explain that such methods may be 'simplified energy calculations' or 'complex dynamic simulations' depending on the project (p. 1088). Lee et al. also emphasise that the aim is to 'identify' renovation measures through calculations or simulations. According to Terés-Zubiaga, Escudero, García-Gafaro, & Sala (2015), identifying 'optimal options' and the potential effects of energy renovation measures may be easier to predict if stakeholders know the thermal performance of the buildings in question before simulation or calculation (p. 390). Morelli, Rønby, Mikkelsen, Minzari, Kildemoes & Tommerup (2012) support this view and suggest monitoring existing buildings as input data for more 'accurate' predictions of energy savings. The underlying assumption in these studies is that energy-saving measures exist and case studies show their effect, so it is 'just' a question of providing stakeholders with information about the benefits. Guy & Shove (2000) call this tendency for a matter of 'getting the message across' (p. 94). Konstantinou & Knaack (2013) describe the importance of having the 'right' information: "If the designer is provided with an indication of how efficient refurbishment options are, it is possible to apply them as part of an integrated strategy rather than try to add measures in later stages, after the strategy is developed" (p. 302). The assumption is that if designers know the benefits of energy renovation measures, then late ad hoc changes to the design can be avoided.

Hence, much of the research approaches energy renovations mainly from a technical standpoint that emphasises technical possibilities and economic benefits. It regards energy renovation as progressing linearly from initiation across some steps, phases, or decisions and ending with the renovated buildings. Guy & Shove (2000) consider this approach as exemplary of a 'techno-economic paradigm' (p. 64), while Frigo (2017) calls it the 'traditional energy paradigm.' The problem with this 'techno-economic' or 'traditional energy' paradigm is that it does not acknowledge or consider the social embeddedness of construction projects (Guy & Shove, 2000; Ryghaug, 2002; Schweber & Leiringer, 2012). Construction projects do not only involve technical solutions and economic considerations, but social interaction constitutes construction projects since people with different backgrounds, aspirations, and knowledge work together to deliver construction projects. Energy renovation projects, similar to other construction projects, are made up of social and technical relations, that is, building projects are made up of social interaction as well as the technical solutions and economic considerations. The field of Science and Technology Studies (STS) focuses on the making of social and technical relations and their mutual constitution. This thesis finds inspiration in science and technology studies to investigate the design of an energy renovation and how ambitions of reductions in energy consumption are handled by the designers.

MOTIVATING A SCIENCE & TECHNOLOGY APPROACH

Techno-economic studies of energy renovations are vital for our understanding of how technical measures can improve the energy efficiency of existing buildings and how stakeholders can achieve most out of the project means available. This thesis takes an alternative approach to energy renovations that emphasises the importance of local, context-specific actions. This approach originates from construction research where scholars draw on social science in their efforts to explore the practical achievements of construction projects. Social science studies of construction projects place social interaction at the centre of their inquiry and relate observations to the societal context in which they occur (e.g. Harty & Dainty, 2016). The aim of these studies is not to reach 'objective' or 'general' research findings; instead, scholars focus on empirical accounts of construction activities and theoretical considerations that might help to understand "the complexity of construction projects as social settings" (Cicmil & Marshall, 2005, p. 523). Schweber (2015) argues that bringing social theory to construction research may help break with taken-for-granted assumptions and opening up possibilities for new insights into construction. According to her, social theory contributes to make construction research a distinct field and creates greater engagement with other social sciences (*ibid.*). Social science studies consider construction projects to be unique constellations of social and material relations. According to Guy & Shove (2000), the planning of energy renovation projects can be seen as socially situated actions located within particular project characteristics which are unique to the specific project (p. 10). This thesis considers energy renovation projects in the same manner by focussing on the socially situated actions performed in the course of a project with unique characteristics. The thesis furthermore draws on these specific and unique characteristics based on theoretical considerations to make analytical distinctions that are valid for other building design processes as well.

Social science approaches are by no means predominant in general energy research (Sovacool, 2014), and until 2012, the amount of 'non-technical' and 'interpretivist' studies in the field of energy and buildings has been rather low (Schweber & Leiringer, 2012, p. 488). Schweber & Leiringer (2012) define non-technical studies as studies that include political, economic, organisational, social and psychological dimension in the relations between energy performance and building processes (p. 484). They continue by defining interpretivist research as studies that assume that meaning mediates human behaviour and that seek to identify types of processes and their expression in particular contexts (*ibid.*, p. 484). Many social science studies include the same 'non-technical' and 'interpretivist' focus as presented by Schweber & Leiringer. Based on their review of literature of energy and buildings research, Schweber & Leiringer (2012) argue that there is a need to expand the scope of construction research to embrace interpretivist approaches as complements to the positivist approach already taking up much of the energy and buildings literature. Furthermore, they argue that construction researchers are in a position of offering social science discussions with intimate knowledge of the industry and technical know-how that is "far superior to stereotypical understandings that are commonly mobilized" (*ibid.*, p. 491). The lack of focus on 'non-technical' dimensions within energy and buildings research leaves a potential for social science studies to shed light on the processes and relations which make up energy-efficient buildings, including the design of energy renovation projects.

This thesis takes a social science approach inspired by the field of science and technology studies (STS). Opposed to the general view on scientific knowledge and technological artefacts, the field of STS does not consider science and technology as 'natural' or having 'simple properties' that define them once and for all (Sismondo, 2010, p. 11). Instead, STS regards science and technology as thoroughly social activities and as actively 'constructed' human products, marked by the circumstances of their production (*ibid.*). STS draws researchers' attention towards the social and technical relations that make up scientific knowledge and technological artefacts. From this perspective, construction projects consist of social and material relations that are mutually constitutive and equally important for scrutiny (e.g. Schweber & Harty, 2010). As a response to a special issue in the journal *Building Research & Information* on 'Visual Practices: Images of Knowledge Work,' Nicolini (2007) brings attention to how such a social and material approach might shed light on design activities:

> *"The contributors to the special issue thus invite one to abandon the simplified understanding of the design activity as a linear process composed of steps or phases, suggesting instead that one approaches the design practice as a social and material choreography fraught with repetitions, detours, and 'U'-turns. It follows that to understand design one needs to bring to the fore both the different actors and their performance as well their interaction, turning one's attention towards understanding the effects of the 'when' and 'how' the different actors enter and exit the scene, how well all the elements (human and material) work together, and to what extent this heterogeneous assemblage is capable of producing a successful show" (Nicolini, 2007, p. 579).*

Nicolini (2007) calls design activities for 'a social and material choreography' to highlight the interrelatedness of the social and material dimensions in design practices. Furthermore, Nicolini suggests to leave the idea of design processes as linear and involving a series of steps or phases, like most the energy renovation literature describes design processes. Instead, researchers should consider design activities as involving 'repetitions, detours, and 'U'-turns.' This statement turns the attention of researchers towards how design processes are carried out by practitioners in specific settings and the aim of following the actors and their performances in doing building design projects.

Science and technology studies direct the research objective towards the 'construction' of a phenomenon. Gherardi & Nicolini (2000) consider this to be:

> *"(…) a situated practice, an emerging property of a socio-technical system, the final result of a collective process of construction, a 'doing' which involves people, technologies and textual and symbolic forms assembled within a system of material relations" (Gherardi & Nicolini, 2000, p. 333).*

This thesis extends their statement to the study of design processes involved in energy renovation project by considering energy renovations as 'a situated practice,' emerging from a 'socio-technical system,' involving a 'collective' of people and things, and a 'doing' which highlights the practical accomplishments that bring energy renovations 'into existence.' According to Nicolini (2007), a typical reaction of social scientists when faced with the complexity of the construction industry is to reduce and simplify issues to a single cause and to suggest better planning, better communication, enhancing trust, or the use of new technologies to prevent such issues (p. 577). Science and technology studies propose an alternative research strategy by attending to everyday activities and 'messy' practices that make up the research objectives in question. Similar to Nicolini (2007), Styhre (2017) argues that business school researchers are inclined to distance themselves from the experienced life world of human beings and the mundane and unobtrusive material world by using idealist concepts (p. 36). According to Styhre, construction management and economics scholars have, compared to business school researchers, only a little problem in delving into 'the nuts and bolts of the lifeworld' and the material resources used by practitioners (*ibid.*). A science and technology approach lead the attention of construction researchers towards the everyday practices, the social and material relations, and the emergence of their research objectives.

Construction projects, including energy renovation projects, offer rich contexts in which to study the constitution of interactions between actors, objects and practices (Bresnen & Harty, 2010, p. 550). Where most social science focus only on social relations, science and technology studies grant material objects a crucial role in the practices of producing knowledge and technologies. In a construction project context, material objects are omnipresent in the design processes and circulate among the involved stakeholders (Harty & Tryggestad, 2015). Also, among other things, enable the creation, sharing and transformation of knowledge (Bresnen & Harty, 2010). Science and technology studies do not merely regard material objects as passive entities used by people. They have an active role in 'making things happen' in construction processes (Nicolini, 2007, p. 576).

Nicolini (2007) argues that if construction researchers pause to observe how material objects enter construction activities in practical ways, then researchers might be able to find out how material objects suit particular purposes and contexts (p. 577).

With inspiration from science and technology studies, this thesis takes an alternative approach to studying the design of energy renovations and emphasises the emergence of 'messy' everyday design processes involving designers and material objects. This research starts from an interest in the practices of designers as they unfold in local and specific design settings and the construction of 'energy performance' through such practices. This study considers 'the social' and 'the material' to be mutually constitutive and emphasises the importance of investigating interactions between designers and material objects to analyse such 'socio-material' relations. To pursue such efforts, this thesis highlights the importance of studying the practical work of making 'an energy-efficient design.'

RESEARCH OBJECTIVE

Energy renovations offer great potential to reduce energy consumption in existing buildings. During the design of energy renovation projects, decisions to introduce energy-saving measures into the projects are crucial to ensure the reduction of energy consumption in the buildings. For this reason, it is vital to understand how practitioners carry out the design of energy renovation projects and how they treat design features related to energy-saving initiatives.

Most of the existing research on energy renovations focus on possible technical interventions, cost-effective estimates, and levels of energy efficiency. Because many researchers consider technical and economic aspects for important, they focus on how to support decision making during energy renovation projects by, for example, developing and demonstrating decision support tools and methods. Those existing studies that describe the design processes involved in energy renovation projects present these processes as theoretical, abstract and detached illustrations of how the processes 'should be' or 'ought to be.' Existing research draws little attention to how designers deal with decisions relating to energy-saving initiatives during the design of energy renovation projects.

Inspired by science and technology studies on construction projects, this thesis draws attention to empirical accounts of energy renovation projects and analytical considerations of how designers deal with initiatives to reduce energy consumption. Science and technology studies of construction projects highlight the local, context-dependent design activities involved in construction projects and regard these activities as consisting of social and material relations. With such an approach, this study extends existing research on the technical and economic aspects by including the social and material aspects of making energy renovation project designs. This thesis emphasises the situated actions in which designers bring an energy renovation project 'into being,' and in this way, studies energy renovation 'in the making.' Based on the insights described above, this thesis scrutinises the following research question:

How do the designers involved in an energy renovation project make energy-saving design features knowable and actionable through social and material design processes?

This thesis focuses on one particular case of an energy renovation project with the purpose of meticulously observing the actions taken by the designers. Based on what the research participants call an 'ambitious and comprehensive' energy renovation project, this study investigates how these ambitions about reducing energy consumption in existing buildings take form in the course of the design processes. That is, how the designers translate ambitions of minimum energy consumption into specific and detailed design suggestions through the design processes.

This thesis finds inspiration in science and technology studies and considers construction projects as social and material accomplishments. Drawing on a particular branch of science and technology studies, namely 'the sociology of associations' (e.g. Latour, 2005) also known as actor-network theory (ANT), this thesis focuses on the relations between designers and material objects as these relations produce an energy renovation design 'in the making.' From this perspective, this thesis regards energy renovation projects as social and material constructs. The sociology of associations draws attention to how asymmetric relations create power relations and how negotiations among actors can explain both success stories and failure within science and technology developments. This study brings attention to how the designers negotiate energy-saving design features and how they use material objects to make these energy-saving design features knowable and actionable.

The research question does not focus on any particular professional group, i.e. only engineers, architects, or energy specialists. Drawing on the sociology of associations, this thesis abstains from defining a priori identities to the actors involved and treats every involved actor on equal terms. In other words, the thesis focuses on how design processes are carried out by designers and material objects involved in such processes and considers all the actors involved in the observed design interactions. This study also abstains from defining a priori what it means to 'reduce energy consumption from buildings through design.' Instead, this study let the designers themselves define how they will achieve the ambitious energy targets and let the object of study be the process of defining 'energy-saving measures.' In this way, the study assumes that energy-saving initiatives do not exist 'out there' and are ready to be implemented without transformation. Instead, this thesis considers energy-saving design features as constructions made by actors and this process involves 'knowing' the design features and 'acting' on these design features. This thesis suggests that knowing and acting on energy-saving design features involve the materialisation of design ideas and negotiated responses to such materialisation. In other words, designers have to make energy-saving design features visible to act on them.

The study revolves around the theme of 'energy-saving design features' as a way to characterise energy-related design. The thesis does not infer that design features for the reduction of energy consumption in existing buildings have specific characteristics. The term 'energy-saving design features' is a way to keep the focus on design which has the intention of reducing energy consumption in particular buildings without defining exactly what these design features might be. As an ethnomethodological principle, this thesis lets the research participants define what 'reductions of energy consumption' means in their particular case and from their point of view.

THESIS STRUCTURE

Chapter 2 presents previous research within three areas. The first focuses on how social science researchers have approached energy-efficient building design. The second examines how design scholars describe design practices. The third presents how social science researchers have approached building designs and how they describe design processes and designers' use of material objects. The chapter ends with the positioning of this study.

Chapter 3 describes the analytical approach and research methods of this study. The thesis draws on the sociology of associations and concepts from the social-science-based building design literature to develop its analytical stance. The thesis builds on an ethnographic study of an energy renovation project which includes video recordings of design meetings, interviews with designers, and review of project materials.

Chapter 4 describes the case which this research revolves around. The case consists of the renovation of four multi-family apartment buildings which are rented out as social housing. The renovation project includes both the renovation of existing buildings and the construction of new apartments. This thesis focuses on the design processes happening at one of the consultancy companies which is responsible for delivering the detailed design of the project to the building client. The analysis focuses on moments in which the designers negotiate energy-saving design features in what the thesis illustrates as 'energy trails.'

Chapter 5 and 6 comprise the analytical part of the thesis. The analysis is divided into two parts since the two chapters foreground different processes. Chapter 5 focuses on how the designers make energy-saving design features knowable and actionable through negotiations. This chapter illustrates how the designers attempt to persuade each other to follow particular suggestions and how these attempts develop into negotiations of interests and ultimately trials of strength. The chapter illustrates energy performance as a matter of competing concerns and a need for designers to enrol allies if they wish to achieve certain interests.

Chapter 6 focuses on how the designers engage with material objects to make energy-saving design features knowable and actionable. This chapter shows how the designers involve themselves in recursive design interactions with material objects in order to solve specific problems. The chapter illustrates how material objects help the designers discover unexpected issues, solve issues, and stabilise particular design features. Even if chapter 5 and 6 foreground negotiations and material objects respectively, both chapters illustrate the design of the energy renovation as involving repeated negotiations and the omnipresence of material objects. The analysis is divided into two chapters to show how energy performance of buildings is a negotiated and socio-material accomplishment.

Chapter 7 discusses the findings of this study based on the analysis. The discussion opens up with a description of how the observations made in chapter 5 and 6 illustrate the 'everydayness' of designing an energy renovation. The discussion then continues with three tendencies observed in the results. First, the designers and energy-saving design features enter into processes of persuasion in which design features change in the course of the project. Second, the designers enter into processes of learning while they design the energy renovation project that leads to discoveries and tests of possible solutions. Third, the designers engage with material objects to fix, that is to stabilise, and to unfix, that is to destabilise, energy-saving design features in the course of their design practices. All three topics are discussed based on the reviewed literature illustrated in chapter 2. Chapter 7 ends with a discussion of what it means to 'know about design' versus to 'know through design' and a summary of the discussions of the three topics.

Chapter 8 concludes the study by summarising the main points of the thesis and their implications for research and practice.

CHAPTER 2

Design Perspectives on Energy Renovations

INTRODUCTION

This chapter provides a backdrop for the thesis by presenting key insights from three bodies of work, namely literature on energy and buildings, literature on design thinking, and literature on building design. These three bodies of literature represent significant sources of inspiration for the present thesis. All of the presented studies take an interpretivist approach to their object of study. Schweber & Leiringer (2012) argue that if construction research should be able to meet the challenges of the low-carbon agenda, then scholars need to complement positivistic research with research focusing on non-technical dimensions, such as the processes, understandings, and motivations which produce observed patterns and systems (pp. 490-1). By taking an interpretivist approach, construction research scholars contribute with the articulation of theory and empirical research as well as being able to bring an intimate knowledge of the industry and technical know-how to debates within social science (*ibid.*, p. 491). The studies in this review have the same features as the ones Schweber & Leiringer (2012) assign to interpretivist studies:

> *"Their focus on process and meaning; their attention to practices and technologies in use; their attention to variations and multidimensional configurations; their concern with questions of 'how' and 'why' rather than with patterns and correlations; their explicit use of theory; and, in some instances, their concern (also) to contribute to theory development." (Schweber & Leiringer, 2012, p. 488)*

The studies draw on social science and are selected because they focus on designs and building designs 'in the making.' A three-step review process has identified the studies presented in this chapter. The first step involved a search for articles in the following journals: *Energy & Buildings* (EB), *Buildings & Environment* (BE), *Design Studies* (DS), *Design Issues* (DI), *Building Research & Information* (BRI), and *Construction Management & Economics* (CME). Literature on energy and buildings has been mostly found in the four journals EB, BE, BRI, and CME. Literature on design thinking has been mostly found in the journals DS and DI. While literature on building design has been mostly found in BRI and CME. The search includes search terms such as 'energy,' 'renovation,' 'design,' 'buildings,' 'process,' 'practice' and related synonyms to these words. For example, synonyms for the word 'renovation' have been 'retrofit,' 'refurbishment,' 'modernisation,' and 'alteration'[1]. Relevant articles have been identified based on a reading of the titles and abstracts and whether the articles emphasise design processes, the design of energy renovations, or design of energy-efficient buildings. The second step involved finding relevant publications amongst the references identified in the first set of publications to follow the on-going discussions within the three bodies of work. Whenever an author appeared more than five times in the first set of identified publications, a search was made on this author to find relevant publications in the same manner as with the first set of publications. The review includes a total of 88 publications.

Since this study revolves around the making of an energy renovation, the first section in this literature review focuses on literature on energy and buildings and how scholars describe design processes in this work. The subsequent sections focus on literature on design thinking and literature on building design processes respectively.

[1] For a discussion on terms used to describe renovations, see Reindl (2017), p. 10; Thuvander et al. (2012), p. 1191; Meijer, Itard & Sunikka-Blank (2009), p. 534.

ENERGY & BUILDINGS LITERATURE

Most of the literature on building energy use draws upon practice theory (e.g. Schatzki, 1996), and this literature originates mostly from an interest in 'practices of consumption' which often is referred to as the 'sociology of consumption' (e.g. Shove, 2003a; Shove, Pantzar, & Watson, 2012; Shove & Walker, 2014). Leading authors in this field are Elizabeth Shove (1998, 2003b, 2010), Kirsten Gram-Hanssen (2010, 2011; Gram-Hanssen & Bech-Danielsen, 2004), and Yolande Strengers (2008, 2011, 2012). Their interest is in how the performance of practices affects energy consumption in buildings, and how these practices might change to support more environment-friendly ways of living. One group of scholars within this field examine the practices of homeowners. Examples of these studies are: how renovation practices and the practices of homeowners intersect and how these practices influence energy efficiency (e.g. Aune, 2007; Bartiaux, Gram-Hanssen, Fonseca, Ozoliņa, & Christensen, 2014; Gram-Hanssen, 2014; Judson & Maller, 2014; Maller et al., 2012; Palm, 2013; Risholt & Berker, 2013; Sunikka-Blank, Galvin, & Behar, 2018; Vlasova & Gram-Hanssen, 2014); how building owners handle energy-efficiency aspects during renovation processes (e.g. Olsson, Malmqvist, & Glaumann, 2015); how homeowners plan to carry out energy renovations (e.g. Fawcett & Killip, 2014); renovation concept based on community partnerships (e.g. Karvonen, 2013); and the motivations and barriers for households in deciding on energy-efficient renovation measures (e.g. Mlecnik, 2010).

Another group of scholars examine how professionals support greater uptake and use of energy-efficient technologies and energy renovations. Examples from this group are: how engagements with craftsmen (and the house itself) affect homeowners to renovate energy-efficiently (e.g. Buser & Carlsson, 2017); how homeowners and installers can learn from each other about how to appropriate and use energy-saving technologies (e.g. Glad, 2012); how knowledge about energy renovations can be shared between groups of professionals and practices, such as researchers, public servants, and energy suppliers (e.g. Gluch, Johansson, & Räisänen, 2013); how building professionals encourage (or disencourage) social change related to the energy system (e.g. Janda & Parag, 2013); how energy efficiency advisers and installers influence homeowners to incorporate energy-saving technologies in renovations (e.g. Owen & Mitchell, 2015); how professionals in the energy renovation industry shape their working practices in relation to clients (e.g. Wade, Murtagh, & Hitchings, 2018).

A third group of scholars in the field of energy and buildings focuses on the design and use of energy-saving technologies. Examples from this group are: How homeowners use energy after renovating their homes (e.g. Risholt & Berker, 2013); how users, producers and intermediaries interact around the design and use of energy-saving technologies (e.g. Rohracher, 2003); how users, designers, planners, and manufacturers negotiate user needs in the design of energy-saving technologies (e.g. Rohracher & Ornetzeder, 2002); the use and design of passive house flats (e.g. Wågø & Berker, 2014).

All these studies from the three groups provide valuable insights to the socio-technical entanglements of energy consumption in everyday life; however, they shed little light on how the design of low-energy buildings is carried out by professionals (with a few notable exceptions, Berker & Larssæther, 2016; Gluch, Gustafsson, Baumann, & Lindahl, 2018). In the following, the section describes how scholars within the field of energy and buildings have approached design processes.

Simon Guy has together with colleagues (Farmer & Guy, 2005; Guy & Moore, 2005; Guy & Shove, 2000) highlighted the importance of studying the design of energy-efficient buildings from a socio-technical approach. According to Guy & Shove (2000), techno-economic approaches to research on the energy-efficient design of buildings have limitations and more sociologically informed approaches may provide more value by illustrating the everyday practicalities of energy-efficient design processes (p. 65). They highlight the major challenge designers face by reversing and re-interpreting generic and 'global' knowledge about energy performance and putting it to work in local, context-specific design problem (*ibid.*, p. 53). In this way, they call for more sociology-oriented studies and focus on local, context-specific design processes.

Guy & Moore (2005) argue that researchers should recognise and analyse green buildings as contingent hybrids where the focus should be on the people and places that shape the design and development of green buildings (p. 3). They draw attention to what practitioners do as a more productive way to study green buildings, rather than conceptualising different ways of designing green buildings. In this way, researchers may shed light on how building design processes involve competing conceptions of environmental issues as well as social and technical processes that frame the processes (*ibid.*, p. 9). Farmer & Guy (2005) also recognise buildings as complex hybrids, which each in their way are situationally specific responses to challenges of sustainability. From their point of view, differing motivations and competing of social commitments of the actors involved in the design and development processes shape the sustainability aspects involved in building designs (*ibid.*, p. 15). Their notion of complex hybrids builds on an idea that technical, organisational and commercial considerations shape sustainable design strategies (p. 29), and therefore, they suggest, it is vital to study the complex social and technical processes involved in the environmental design.

A few authors suggest that architects and engineers might approach energy-efficient design differently. Guy & Shove (2000) argue that engineers might approach energy demand as something to be calculated and quantified, while architects might regard energy performance as an integral part of the design, connected to form and performance of the whole project (p. 39). Fischer & Guy (2009) argue that architects need the consultancy of engineers early on in the projects in regards to energy efficiency and that the architect understands less and less of the engineers' activities as projects develop. They furthermore suggest that tensions may occur in situations with time pressure between architect and engineers based on architects' strive towards bespoke solutions and engineers' standardised responses to issues (*ibid.*, p. 2591). Hojem & Lagesen (2011) argue that engineers, even though they highlight the importance of energy efficiency, mostly associate environmental concerns with fulfilling legal regulations, and they draw on technical codes and regulations to define what it means to do environmental concerns (p. 15). These studies indicate that building professionals may approach energy-efficiency issues differently and that these different approaches may lead to tensions during design processes.

Similar to Guy & Moore (2005), Zapata-Lancaster & Tweed (2014) argue that it would be more valuable to study what designers do instead of studying what they should be doing. According to their ethnographic study, design for energy performance does not invoke the same relevance amongst the stakeholders. Accordingly, their understandings and expectations differ and continue to do so throughout the design process (*ibid.*, p. 137). Building professionals seem only to design for energy performance according to meet minimum standards. According to Zapata-Lancaster & Tweed, design processes are situated in a context of purposes and meanings which might go against expectations of achieving low-energy performance. Another study by Zapata-Lancaster (2014) exemplifies the difficulty of designing energy-efficient buildings when designers need to balance energy targets with project requirements, capital and life-cycle cost, buildability, maintenance, spatial needs, as well as the experience and skills of builders during construction (p. 145). Her study shows that designers pay less attention to energy performance targets because of a focus on capital cost reductions. The studies of Zapata-Lancaster & Tweed show how the ethnographic approach to studying energy-efficient building design may lead to understandings of design processes which are different from what policy recommends or 'best practice' suggests.

A recent study by Eidenskog (2017) observes building professionals and their struggles in handling energy-efficiency goals during building design processes. Her study focuses on energy modelling and how energy modelling affects the design process. According to Eidenskog, the professionals do not understand the calculations behind the energy models, so they choose to trust the expertise of the energy consultant. Practices of energy modelling create tensions in the project when architectural design solutions come into conflict with energy efficiency goals (*ibid.*, p. 224). Her study also shows how energy models 'black box' issues in some situations, while bringing out complexities in other situations: When a new energy consultant enters the project and open up an otherwise accepted and settled energy model, new uncertainties arise, and the professionals are forced to trust the new energy consultant (*ibid.*, p. 229). In this way, her study shows how the outcome is not given during the design of energy-efficient buildings, or any other buildings for that matter. Certainty must be, according to Eidenskog, achieved through actions of the designers. Her study provides compelling insights into the dynamics of developing energy efficient building designs. Of particular interest is the question of what energy modelling can do to the design process.

The actual design processes associated with energy renovations has gained little attention, except for a few studies. A study by Reindl (2017) shows how professionals treat questions about energy performance during the design and planning of three renovation projects. Reindl follows the design meetings among the involved stakeholders and based on inspiration from practice theory; she focuses on how routines, technology, meanings and knowledge develop during the projects. She focuses on the negotiations among the stakeholders and how energy-efficiency measures become part of these negotiations and lead to the inclusion or exclusion of particular measures. These findings are in keeping with Palm & Reindl (2016), who argue that building energy performance of a building depends on the social relationships, discussions, negotiations and agreements amongst the professionals involved during the design and planning processes (p. 249). Their study shows how the renovation process is locked into the inertia of the professionals' practices in which they do 'what they always have done' and in this way repeat the same practices over and over again. The inertia makes it difficult for the implementation of energy efficiency measures, even if the projects have explicit energy reduction goals. Palm & Reindl (2018) also show how a decision regarding a heating system changes from being 'too expensive' to being 'financially acceptable' during the design process. In this way, the authors highlight how barriers to energy efficiency and decisions in renovation projects are part of specific social contexts in which actors regularly interact and negotiate what to include and exclude in the projects (*ibid.*, p. 63). Based on their studies, Palm & Reindl (2018) argue that energy renovations are multifaceted, and a process approach to the studying energy renovations can provide complementary insights to studies based on questionnaires or interview data. In keeping with Reindl (2017), this thesis takes a process-oriented approach in examining the negotiations professionals make about energy efficiency.

The studies mentioned above consider energy as something that has to be made known by "rendering it visible" (Guy & Shove, 2000, p. 36). Making energy known is a matter of interpretation of 'global,' 'universal,' and 'objective' knowledge in local, context-specific design problems embedded in social and physical settings (Guy & Shove, 2000; Guy & Moore, 2005; Farmer & Guy, 2005). From this perspective, energy-saving design features emerge out of design practices and are not exogenously given. Even if building clients demand energy-saving measures, designers do not necessarily know about these requirements (Palm & Reindl, 2016: 254). Energy-saving design features emerge out of designers' practices and have to be made known to the designers. For example, Zapata-Lancaster (2014) describes how designers define energy metrics to know energy-saving features, such as CO2 emissions reduction, percentage renewable energy use, and U-values. Designers have to make energy-saving design features known if they should be able to make energy actionable.

The studies also highlight how low-energy buildings are 'wicked problems' (Rittel & Webber, 1973) because their complexity is not amenable to straightforward problem-solving methods (Zapata-Lancaster & Tweed, 2014, p. 138). Designing energy-efficient buildings and renovations is not a linear process, and the design and energy goals may change along the process (Palm & Reindl, 2018, p. 63). Even if the design of energy-efficient buildings may seem smooth sometimes, previously accepted and settled design features may become re-opened during the design process (Eidenskog, 2017, p. 229). Furthermore, designers have to tackle energy-efficiency while they also tackle a multitude of other design features such as project costs, buildability, maintenance, spatial requirements, and preparation of construction sites (Zapata-Lancaster, 2014, p. 145). Tensions may appear between energy-saving design features and the many other design aspects designers need to handle during building projects. Lastly, the studies argue that the design of energy-efficient buildings relies on social and material processes. Although, the studies differ in regards to whether social and material relations are 'framing' and provide 'context' for design processes (e.g. Guy & Moore, 2005; Farmer & Guy, 2005), or design processes are 'entanglements' of social and material relations (e.g. Eidenskog, 2017).

In attempts to understand the design of energy renovations, this thesis finds inspiration in the design literature on how designers work and make their object of inquiry knowable and actionable. The next section describes some of the main points presented by design scholars.

DESIGN THINKING LITERATURE

Within the design literature, scholars approach the study of design processes from mainly two perspectives. One of the perspectives has been called ‘design methodology’ and scholars taking this approach attempt to theorise the ‘core phenomena’ in design processes and assist designers in their problem-solving processes (e.g. Le Masson, Dorst, & Subrahmanian, 2013). Many of these studies present theories of design processes based on formal, mathematical languages with a view to transcend disciplinary differences between designers and create a common vocabulary for general design problems, tasks and approaches (e.g. Hatchuel, Le Masson, Reich, & Subrahmanian, 2018). The ‘design methodology’ approach to the study of design processes abstract analysis from the practical making of designs. This thesis attempts to gain insights into the practical making of an energy renovation and draws on the second approach to the study of design processes called the ‘design thinking’ movement.

Studies within the literature on design thinking aim not to simplify the object of study and cherish the multiple perspectives and rich pictures of design activities that multiple approaches to the study of design can provide (Dorst, 2011, p. 521). This take on design processes bears witness to an academic interest in the professional practice of designers, including, their skills, competences, and reflections (Johansson-Sköldberg & Woodilla, 2013). The academic interest takes it starting point in the design practice and develops theory and practice based on what can be observed or learned from design practices.

The body of literature on designerly thinking began as a proclamation against the rational and systematic approach taken by proponents of the design methodology approach. Critics from the design community claim that models of design methods build on inappropriate theories of problem solving and rational behaviour which do not relate to designers’ intuitive ways of thinking (Cross, 2011). According to scholars taking the design thinking perspective suggest that designers have a particular way of thinking, that is, there exists a ‘designerly way of knowing’ different from the scientific and scholarly ways of knowing (Cross, 1982; Lawson, 1979). Design thinking scholars argue that the rational models (from the design methodology studies) ignore the design content, the designer, and the design context, as well as claim validity for every designer, all kinds of design problems, and all kinds of situations (Dorst, 2008, p. 5). According to the design thinking scholars, this does not represent design practices. As an alternative view, scholars of designerly thinking propose to discuss design as a practice and how designers learn, develop and teach the skill of design. This thesis approach design in a similar fashion by considering design as something that is performed in practice.

The academic interests of designerly thinking scholars typically focus on the skills, types of knowledges, and types of evaluations designers make during design activities (e.g. Cross, 2007; Lawson & Dorst, 2009). Some authors call it the cognitive processes of designers; however, they relate it to how these cognitive processes are manifested in design action (e.g. Cross, Dorst, & Roozenburg, 1992). It is the interplay between design practice and the thinking, reasoning and reflection which goes on while designers make designs which are of interest. One well-known proponent of design as a reflexive practice is Donald Schön (1983). According to Schön, design is a reflective conversation with the situation in which the designer shapes the situation, the situation "talks back" to the designer, who then responds to what the situation "tells" him or her. This makes the designer "reflect-in-action" when he or she is confronted with surprises in situations of uncertainty, instability, uniqueness, and/or value conflict (*ibid.*, p. 50). Designers' ability to be creative is situated in the interplay between his or her actions and the reflection he or she makes during these actions. This thesis approaches the study of energy renovations in a similar way, since this study focuses on how designers make energy-saving measures knowable and actionable through their design practices. Design thinking scholars focuses on reflection within the 'materials of the situation' which this thesis attempts to do concerning a specific case of an energy renovation.

Another topic these scholars focus on is the nature of design problems. According to Cross (1982), it is well-known that design problems are ill-defined, ill-structured, and 'wicked' (Rittel & Webber, 1973). This makes design problems generally complex, unique and difficult to solve. Moreover, designers explore problems and solutions together and the two influence each other in the design process (Dorst & Cross, 2001). This means that design problems change and transform in the course of the design process, similarly as the solutions change in accordance with the problems. What all the authors agree is that design problems are rarely well-defined and structured, and almost all design problems involve surprises and uncertainties. Design problems are never completely given prior or during the design, but designers actively construct and 'frame' the problem during their solution propositions by deciding what to attend to and how (Schön, 1983, p. 40). This thesis considers the design of energy-efficient buildings as an ill-defined, ill-structured, and wicked design problem since the design of low energy performance depends on the uncountable number of ways of approaching such a task. Furthermore, this study focuses on how the designers frame the design problems that they experience as well as how the design problems change in the course of the design processes. This calls for attention to the design practices of carrying out energy renovations.

An important aspect of design, which design thinking scholars highlight is the role of drawings, sketches, models, and other artefacts in designers' processes of reasoning. Cross (2011) points out that design can never be a complete mental process – designers need to rely on external representations which help them to explore design problem-solutions and store tentative design proposals. Designers are immersed in a "material culture" in which they are able to "read" and "write", that is, to understand messages which objects communicate and to create new objects which embody new messages (Cross, 2007, p. 26). This is what Schön (1983) calls the "materials of the situation" in which the designer can reflect-in-action. Since the interaction between designers and the materials of the situation is important for the realisation of design ideas, this study of the design of energy renovations focuses on such interaction to understand how the designers come to know and act based on these designers-materials interactions.

Design thinking scholars emphasise the practice of designers, their everyday routine design activities, and how designers deal with design problems and possible solutions. This study adopts this focus and investigates how the designers working on an energy renovation carry out their everyday practices and how they handle energy-saving design features. Design thinking scholars provide theoretical contribution based on empirical studies of how designers reflect-in-action, how they approach design problems, and how they make solutions and problems knowable. Drawing on this research, this thesis attends to how designers actually carry out designing a particular energy renovation.

The next section describes how scholars that study building design processes approach design processes as well as relations between designers and material objects.

BUILDING DESIGN LITERATURE

Although the literature on energy and buildings has a strong focus on understanding end-user consumption patterns and the design literature focuses on general design processes, there is also a growing body of research, drawing on science and technology studies (STS), directed towards understanding design practices and their implications. This theme figures more prominently in research on building design in general, i.e. in studies not explicitly concerned with energy-related issues. Most of this body of work focuses on design practices and study the practical making of building designs. The literature covers a range of different research topics. Some examples are: how digitally mediated design work is carried out (e.g. Çıdık, Boyd, & Thurairajah, 2017; Dossick & Neff, 2011; Harty, 2008; Harty & Whyte, 2010; Koch & Beemsterboer, 2017; Neff, Fiore-Silfvast, & Dossick, 2010; Whyte & Lobo, 2010); how architectural competitions are carried out (e.g. Gottschling, 2017; Kreiner, Jacobsen, & Jensen, 2011); how engineers coordinate work across country borders (e.g. Ramalingam & Mahalingam, 2018); interactions between professionals and building users (e.g. Luck, 2010); and different ways of collaborating such as partnering (e.g. Bresnen, 2010; Gottlieb, 2010).

Much of this work draws on the sociology of associations (e.g. Latour, 2005), or actor-network theory as it is also called, in their study of the social and material processes of building design. Since all of these studies contribute with perspectives on the practices of building design, they bring valuable insights to understandings of building design processes in a range of settings. The two following sections emphasise research that focuses on the negotiation of interests as well as the many different roles material objects play in making building designs knowable, actionable, and real.

NEGOTIATIONS & PROCESSES

The following studies illustrate how design processes are fluid, dynamic, and sometimes lead to unexpected realisations for the involved project members. For example, Yaneva (2008) shows how existing buildings during renovation processes may not be subservient objects which passively submit to renovation interventions. Instead, her study describes existing buildings as mediators or actors which may be disobedient, resist attempts of control and surprise the involved project members. Yaneva presents renovation processes as involving difficulties, unpredictable turns, surprises and drifts and terms the process for 'renovation in the making' (*ibid.*, p. 10). This thesis regards renovation processes in the same manner as uncertain processes where even buildings or other objects may be disobedient and bring surprises to the project participants.

Another aspect of design processes which previous scholars have highlighted is the political dimension of design. According to Schmidt, Sage Eguchi & Dainty (2012), everyday practices of designing lay in the intersection between what they call 'Big Politics' and 'micropolitics.' Big politics are attempts made to formalise, codify, and institutionalise political decisions, values and actions, whereas micropolitics are attempts made to open up politics to new actors, find space for 'others' to speak and perhaps transform collectives (*ibid.*, p. 76). Their study suggests that political ideologies and institutions are knitted together with the 'sites of contestation' in which design processes happen. Designs are descriptions of reality and, as the authors state, describing is performing 'good or bad' and is always an ethical and political act (*ibid.*, p. 76). Because of a possible conceptualisation of building design as a tension between Big Politics and micropolitics, they argue that architecture would be better thought of as a verb and not a noun – always on the move (*ibid.*, p. 75). According to the authors, building design processes are not easy, but the everydayness of design is arduous and moves between two types of politics. This thesis regards design processes as political, but in the sense that actors have different interests and competing interests may lead to debates over 'good and bad' or 'right and wrong.' Design processes may be an arena for conflicting interests and the power to persuade others to follow one's interest.

Boudeau (2013) studies the interaction between an engineer and an architect and finds that coordinating activities during design is based on mundane and everyday methods. Discrete coordination interactions might seem banal but are central to the design processes. She draws attention to the importance of analysing the situated context of design discussions to capture the informal and minute interactions which coordinate design tasks among the two professionals. The study by Boudeau shows how it is vital to study designers as they perform designs up close and follow their interactions meticulously.

A recent study by Kurokawa, Schweber & Hughes (2017) shows how the identity of project participants, in their case client actors, is not static nor uniform in design processes. Project participants may be directly involved and present during design, but they may also be in a 'mediated presence' through the use of objects (*ibid.*, p. 910). In this way, client preference can figure in the design negotiations in an ongoing and dynamic manner. Kurokawa et al. argue that design negotiations do not revolve around one issue at the time, but their study shows how issues sometimes shift in focus and produce a range of related issues (*ibid.*, p. 915). Following this, design issues may morph into several other design issues. They suggest that materialisation of design decisions during the process fix some decisions while keeping others open for negotiation. In this way, designers move from less materialised and more design possibilities to more materialised and fewer design possibilities over time. They thereby suggest that design decisions are not made by individuals, but rather by relations between human and nonhuman actors, that is designers and objects, in which stabilise design decisions over time.

The studies mentioned above illustrate how building design processes are unpredictable, political, and involve mundane coordination practices. During building design, the building itself may become disobedient and resist attempts of control (Yaneva, 2008). Such unpredicted actions can change the status quo in design projects and surprise designers with unexpected design conditions. The studies also highlight how design processes are political (Schmidt et al., 2012) and involve negotiations of interest (Kurokawa et al., 2017). Intentions of 'Big Politics,' such as policy efforts to reduce energy consumption in buildings, are part of design processes as much as 'micropolitics,' such as the definition of actors involved in a given design issue, also is part of design processes.

Moreover, when different political interests meet, design processes involve negotiations. Building design processes involve negotiations around design issues where specific interests may be privileged over other interests (Kurokawa et al., 2017, p. 920). If researchers want to shed light on such processes, one way is to study the everyday, mundane, informal and often banal performance of coordination practices of designers (Boudeau, 2013). The studies also highlight how building design processes are social and material achievements. In renovation projects, the building itself can play a crucial mediating role (Yaneva, 2008). Building design processes are the effects of dynamic networks of human and nonhuman actors (Schmidt et al., 2012; Kurokawa et al., 2017). From this perspective, individual persons do not make design decisions, but networks of human and nonhuman actors and design decisions may become fixed in material objects through ongoing design negotiations (Kurokawa et al., 2017).

The next section describes how building design scholars have addressed the role of material objects in building design processes.

THE ROLE OF MATERIAL OBJECTS

The following studies investigate the role of material objects in the creation of designs. The authors regard material objects as vital for knowing and acting on design features. For example, Yaneva (2005) shows how architects fabricate models and move between models with different scales to progressively define and refine the building design. She argues that the scaling activities of the architect allow them to achieve two different states of the building design simultaneously: A state where the building design is 'less-known,' abstract and comprehensive, and a state where the building design is 'more-known,' concrete and detailed (*ibid.*, p. 867). The models materialise both states and architects move between models to know more about the building design; however, the models will never complete the building design. Instead, they always leave some aspects unknown. According to Yaneva, the material practices of scaling allow architects to partially see design features, where the practices hide some features and reveal others (*ibid.*, p. 869). Material objects are paramount for the architects' ability to grasp the building design. She argues that building designs emerge and come into existence through the material practices of making models. Designing buildings is about "knowing it more and knowing it less at the same time" (*ibid.*, p. 870). Designers never grasp the building design in one material object, on single state, one model, but they always have multiple material objects, many models, compositions of many elements which comprise the building design, what Yaneva calls a 'multiverse' rather than a 'universe' (*ibid.*, p. 871). Her study shows how building designs are made knowable in the hands of the architects and, as scales shift, the designs become real. Building designs are made real through material practices of designers. Material objects help designers know some aspects, but might also conceal other aspects. Designers are only able to act on their knowledge of the building design when the design is made available to their sight. In the hands of the designers, building designs emerge from material practices with objects and allow them to 'partially see' the future building.

Bendixen & Koch (2007) describe other types of engagements with material objects. Their study shows how designers use drawings in three particular ways. First, they show how drawings may be 'inscribed' (Akrich, 1992) with interests which makes them 'political instruments.' In their case, drawings influenced a potential sponsor to become part of the building project. Second, drawings may have 'prescriptive' effects (Akrich & Latour, 1992) which allow designers to discuss certain topics because the drawings illustrate these aspects of the design. In the case presented by Bendixen & Koch (2007), the designers find it difficult to discuss rooms which are not visible in the present drawings. The prescription of the drawings does not enable the designers to discuss the rooms, and they have to turn to other drawings to be able to talk about the rooms. Third, drawings may act as 'conscriptions' (Henderson, 1991) where they contribute to the mutual shaping of knowledge which then is encoded into the drawings. The ability to conscribe also involves the parallel process of inscription and prescription (Bendixen & Koch, 2007, p. 43). Bendixen & Koch argue that drawings are at the same time malleable and stable during design processes. Drawings can further political purposes, bring processes to a halt or bring them further, and interactions between designers and drawings may be mutually enforcing (p. 52). The use of material objects may have different characteristics depending on the situation, as well as how designers use material objects.

Focusing on organisational knowing and learning, Whyte, Ewenstein, Hales & Tidd (2007) investigate design work in two different firms: a capital goods manufacturer and an architectural firm. According to their study, material objects are treated by the designers as either frozen or fluid. When designers treat materials as frozen, the material is considered unavailable for change. In their case, materials are used in a frozen manner to legitimise consultation of specific actors, used as references, or for tactical and political reasons (*ibid.*, p. 26). When designers treat materials as fluid, they regard the materials as open and dynamic. Fluid materials allow the designers to define design problems, explore possible solutions, as well as comment, make input and modify the materials. Based on these two analytical concepts, Whyte et al. argue that designers in their case move in patterns or rhythms of 'freezing,' 'unfreezing,' and 'refreezing' design features in material objects and hence, their knowledge about the building design evolves (*ibid.*, p. 19). According to the authors, moments of 'freezing' and 'unfreezing' design features are important turning points in design processes where design features may be open for negotiation or debates about design features may be closed down.

In continuing to analyse work performed in the architectural firm, Ewenstein & Whyte (2009) suggest the consideration of the use of objects from multiple dimensions. According to them, the literature describes objects as relatively stable or in flux, as abstract or concrete, as used within or across practices (*ibid.*, p. 7). Their study shows how visual representations become material instantiations of an epistemic object (e.g. a building design). The visual representations are used to manipulate the epistemic object by stabilising some design features and in evolving others (*ibid.*, p. 26). The designers' knowledge of the project develops in the interaction with the material objects, and the building design gets defined and refined during the process. Their study shows how material objects may have an epistemic role (Knorr Cetina, 1999) in the design process where they continue to indicate a lack or incompleteness which provoke unfolding of new material objects and questions (Ewenstein & Whyte, 2009, p. 7). In their role as epistemic objects, visual representations, they argue, actively demand development or definition, and as they evolve, they raise some questions and answers other questions (*ibid.*, p. 27). Based on their study, Ewenstein & Whyte argue that the material objects observed do not develop knowledge across boundaries as 'boundary objects' do (Star & Griesemer, 1989), nor do they represent 'immutable mobiles' (Latour, 1986) by circulating 'accepted truths', rather they constantly unfold, evolve and are essentially mutable objects (Ewenstein & Whyte, 2009, p. 27). Even though some material objects may be characterised by continuously unfolding, Ewenstein & Whyte also highlight that designers may treat some objects as 'technical objects' (Rheinberger, 1992) which are not modified, are held constant and provide reference points during the design process. The multidimensional approach presented by Ewenstein & Whyte (2009) is a valuable take on the role of material objects because such a take allows scholars to appreciate the changing dynamic of different kinds of interactions with objects. Based on their study, researchers may consider several dimensions: relatively stable or in flux, abstract or concrete, used within or across practices, immutable or mutable, raise questions or close design features, and perhaps more dimensions can be added to this list.

In three papers, Tryggestad & Georg (2009; 2011; Tryggestad, Georg, & Hernes, 2010) present evidence from a case study where material objects play a vital role in the design and construction of a skyscraper. Georg & Tryggestad (2009) show how project management roles emerge from interactions between humans and the devices they elaborate and use which in turn shape the project management roles (p. 976). In this way, project management depends on and influenced by material objects. Tryggestad, Georg & Hernes (2010) argue that material objects establish the materiality and the context for developing design ambitions during construction projects, as well as helping designers to resolve rising tensions which arise from conflicting design ambitions (such as aesthetic versus technical ambitions). According to the authors, tensions between design ambitions resolve through 'trials of strength' (Latour, 1987) as the object (the building) is elaborated and circulates across sites in the project as sketches, drawings, models, or something else (Tryggestad, Georg & Hernes, 2010, p. 695). Their study highlights the performative role of material objects in actively transforming the values, strategies, interests and beliefs present in construction projects. As presented by Tryggestad & Georg (2011), design features become progressively elaborated in construction projects into multiple material objects, such as sculptures, sketches, drawings, pictures, models, budgets, concrete and steel which at some point stabilises a building design (p. 195). The three studies highlight how material objects shape design ambitions, project management roles, logics and identities, as well as contributing to the continuously elaboration and stabilisation of the building design.

Similar to Whyte et al. and Ewenstein & Whyte, Whyte, Tryggestad & Comi (2016) are interested in how designers develop and share understanding. Whyte, Tryggestad & Comi describes building design projects as involving 'cascades of visual representations.' That is, visual representations which are "collated into and presented as a set of reified and hybrid forms through the design and project work" (*ibid.*, p. 126). Building design processes, according to the authors, emerge from and are developed through what they call 'paper-work' or/and 'model-work.' The visual representations allow project participants to share and develop understandings in the course of construction projects. Such projects end with 'consolidated cascades' of visual representations (*ibid.*, p. 116) which show evidence of the paper- and model-work leading up to these visual representations. Whyte et al. (2016) argue that interactions with visual representations allow the designers to revise project budgets as well as make and remake strategic decisions (p. 126). The study presented by Whyte et al. illustrates how engagements with material objects do not 'just happen' but require work and often much 'paper-work' or 'model-work' have to be done for designers to collect, gather, and present 'cascades of visual representation,' in other words, illustrations of building designs.

Designers do not only work with material objects to develop more knowledge about the building design or share understandings of the building design with others. Designers also engage with material objects to make strategic actions, or, as Comi & Whyte (2017) describe, to make realisable courses of action for the future. This thesis considers the realisation of an energy renovation project as such a possible future. Comi & Whyte underline the intimate relationship that practitioners have with material objects when constructing the future by proposing to call their take on such actions for 'future making.' In this way, they stress how designers 'make' a future while they work with material objects. According to them, there is no separation between thinking and making the future – it happens at the same time. Comi & Whyte suggest that material objects are necessary for practitioners can be able to take actions towards the future because the materiality of the objects (the 'now') ties to the immaterial (the 'not-now') of the future (p. 24). In this way, material objects, and the practical work in making them give form to abstract imaginings of the future - what is 'not yet' – and crafting realisable courses of action (p. 2). The materiality of the objects allows designers to make 'the future' amendable for further work, and in so doing, the designers may become aware of uncertainties they did not know before (p. 22). Designers act towards imaginings of the future based on their engagements with material objects. Comi & Whyte describe it as a way of 'sensing the future' through such engagements. Seen from this perspective, building designers may not only make design features knowable through engagements with material objects, but they may also act and decide on strategic actions for the future based on such engagements.

Returning to the study by Kurokawa, Schweber & Hughes (2017), they not only describe how negotiations happen during building design processes, but they also present crucial insights about relations between designers and material objects. Kurokawa et al. describe how material objects can fix design decisions during design processes. They distinguish analytically between mediators (objects which change things) and intermediaries (passive objects that transport messages without changing it) (*ibid.*, p. 910). However, they also argue that intermediaries, or what they also call 'devices,' are important means to stabilise building designs and make them durable. Based on their study, they suggest that prior project negotiations can be incorporated into material objects which serve to fix particular details and render certain design features non-negotiable in subsequent discussions (*ibid.*, p. 923). In this way, an 'overlay of devices' contributes to the stability and the durability of building designs. Kurokawa et al. suggest that material objects also allow for 'action at a distance' (Latour, 1987) by 'carrying decisions taken at one point in time into subsequent ones' (p. 923). From their perspective on material objects, the durability of design features may come from their materialisation into objects. Additionally, the 'strength' of design features is an effect of the 'overlay of devices' which make such features durable (or perhaps not durable).

The studies presented in this section argue that building design consists of material practices. From this perspective, designers develop knowledge about and insights into building design features by interacting with material objects. Engagements with material objects allow designers to 'sense' the building design (Comi & Whyte, 2017). The objects materialise and reveal some design features, while they hide other features (Yaneva, 2005). In this way, material objects only allow designers to see building designs partially. With their materiality, objects give form to abstract imaginings of what is 'yet-to-be' (Comi & Whyte, 2017) and therefore crucial in knowing and acting on ideas about the future.

The studies highlight how engagements with material objects may display different kinds of dimensions. Material objects may allow building designs to become 'more-known,' detailed and concrete, while remaining 'less-known,' abstract and comprehensive (Yaneva, 2005). Material objects may become malleable or stable during design processes, or both at the same time (Bendixen & Koch, 2007). Material objects can become frozen or fluid (Whyte et al., 2007), or as stable or in flux, as abstract or concrete, and used within or across practices (Ewenstein & Whyte, 2009). Material objects may unfold, evolve and be mutable or remain unchanged, held constant and provide reference points (*ibid.*). Lastly, they may contribute to design processes as either mediators or intermediaries (Kurokawa et al., 2017). These many dimensions of material objects and their use show their multiplicity in building design processes.

The studies also show how material objects can become political instruments (Bendixen & Koch, 2007) or used to freeze design decisions at least temporarily (Whyte et al., 2007), or fix design decisions to make them more durable in subsequent negotiations (Kurokawa et al., 2017). The studies indicate a constant movement between stabilisation and development of design features when designers engage with material objects. Material objects can stabilise design features while they can evolve other design features (Ewenstein & Whyte, 2009; Tryggestad & Georg, 2011). They may help designers to resolve tensions between design ambitions (Tryggestad, Georg & Hernes, 2010). Material objects allow designers to develop and share understandings of the building design (Whyte, Tryggestad & Comi, 2016).

Moreover, they carry decisions from one point in time into another (Kurokawa et al., 2017). All these abilities of material objects show how building designs are dependent on material practices. When designers engage with material objects, they can make design features knowable and actionable.

By now, the chapter has outlined previous research on energy and buildings, design research, as well as on building design processes and the role of material objects – the next section summaries these insights and positions the study in the previous research.

POSITIONING OF THE STUDY

Most of the social science studies on energy and buildings draws on the 'sociology of consumption' movement (e.g. Shove, 2004) where consumption practices are at the centre of attention. Drawing on practice theory, many of these scholars seek to explain patterns of consumption and explore the possibilities for changing them. Although these studies provide valuable insights into the socio-technical entanglements of human energy consumption in buildings and are important studies if we want to understand how to reduce the human impact on our environment, they primarily focus on the end-user (household) consumption practices. There are very few studies that focus on how energy-efficient building designs develop, and many of these studies employ practice-theoretical assumptions when approaching the design of buildings (e.g. Guy & Shove, 2000; Palm & Reindl, 2016; Reindl, 2017). These studies contribute with insights into how meanings, technologies, routines, and knowledge developed over time as social agents reproduce practices again and again. Research pays little attention to how the design of energy-efficient buildings is carried out in everyday design practices involving mundane interactions between designers and material objects. This thesis contributes to such research efforts by investigating everyday design practices involved in an ambitious energy renovation project from a 'sociology of associations' (e.g. Latour 2005) perspective.

Where much of the social science studies of energy and buildings draw on practice theory, several studies within research on building designs find inspiration in the sociology of associations. The empirical settings of these studies vary and include, among other things, the renovation of an existing building (Yaneva, 2008), the design and construction of skyscrapers (e.g. Tryggestad et al., 2010), the design of a university building (Kurokawa et al., 2017), and the design of an exhibition hall for a museum (Yaneva, 2005). Even if the settings of the studies vary, none of them has yet shed light on the design of energy renovation projects. The research object of the studies also differs and includes, among other things, how architects make a building design knowable and real (Yaneva, 2005), the role of project management (Georg & Tryggestad, 2009), the transformations of design ambitions and project goals (Tryggestad et al., 2010), and how clients are engaged in building design (Kurokawa et al., 2017). These studies represent a range of different research objects; however, no studies have yet examined how designers treat energy-saving design initiatives from these perspectives. No studies have investigated how designers make energy knowable and actionable during design processes. This thesis contributes to research on building design by studying how energy-saving design features are 'made into being' during an energy renovation project.

Within the literature on energy and buildings, this thesis draws on the social-science-based approach inspired by science and technology studies by focusing on how energy performance becomes a social and material accomplishment. Scholars within the energy and buildings literature consider energy-efficient building designs as a practical achievement made through everyday practices (e.g. Guy & Shove, 2000). This thesis extends such a perspective to the design of energy renovation projects. Energy and buildings scholars suggest that engineers and architects may approach the design of energy-saving features differently (e.g. Fischer & Guy, 2009; Hojem & Lagesen, 2011). This study examines how designers with different professional backgrounds work together to develop energy-saving design features based on the assumption that their different backgrounds may foster different ways of approaching energy efficiency issues. Furthermore, this thesis examines how discussions and negotiations (e.g. Palm & Reindl, 2016) among designers emerge during the design of an energy renovation. Taking a process perspective (e.g. Palm & Reindl, 2018), this thesis examines how the designers handle energy-saving design features through their design practices and contributes with a sociology of association perspective on the making of energy renovations.

From the design literature, this thesis draws on the interest in design practices as they are performed by designers while they interact with the 'materials of the situation' (Schön, 1983). The design thinking literature focuses on how designers reflect-in-action, and this study extends such an interest to investigate how designers make energy-saving design features knowable, and then how they act on such knowledge. The design literature describes the interaction between designers and materials as a 'dialogue,' with this as an inspiration, the thesis examines the mutual constitution of the designer, the design problem, the design solutions, and the materials of the situation. This requires a focus on how designers engage with material objects, that is the 'material culture' of designers (Cross, 2007). This thesis contributes to the design literature with the empirical example of building design and a focus on how architects, engineers and construction architects develop knowledge through their design practices.

The focus on material objects and negotiations in this thesis originate mostly from the literature on building design, where most scholars approach their object of study from the sociology of associations perspective. In this way, this study draws on the notion of social and material entanglements of building designs, and extends such a view to the design of energy renovations. Building design scholars highlight the political aspects of designing buildings and architecture (e.g. Bendixen & Koch, 2007; Schmidt et al., 2012). This thesis extends such insights by considering the making of an energy renovation for a political endeavour involving translation of interests, competing concerns and trials of strength. Building design scholars also highlight the importance of interactions between designers and material objects in making building designs knowable and actionable (e.g.

Comi & Whyte, 2017; Ewenstein & Whyte, 2009; Yaneva, 2005). This study turns towards interactions between designers and material objects in the attempt to understand how they make energy-saving design features knowable and actionable. Building design scholars emphasise how material objects provide instability, openness, and fluidity in design (e.g. Whyte et al., 2007; Ewenstein & Whyte, 2009), as well as stability and durability (e.g. Tryggestad, Georg & Hernes, 2010; Kurokawa et al., 2017). This thesis extends such insights and examines how material objects stabilise and destabilise design features as the designers work with them in the course of design processes.

The next chapter describes the analytical approach taken in this thesis based on the sociology of associations and the research methods used to study a specific energy renovation project.

CHAPTER 3

Analytical Approach & Research Methods

INSPIRATION FROM THE SOCIOLOGY OF ASSOCIATIONS

This thesis draws on literature from the 'sociology of associations' (e.g. Latour, 2005) as its analytical approach and inspiration for choosing research methods. The sociology of associations is also called 'actor-network theory' and abbreviated ANT in many studies. In this study, the term 'sociology of associations' is used to highlight the importance of studying associations, that is, relations. The sociology of associations originates from an interest in how scientists produce scientific facts and how engineers develop innovations (Sismondo, 2010, p. 81). The approach grows out of a group of studies sometimes referred to as the 'laboratory studies' (e.g. Knorr, 1977; Latour & Woolgar, 1979; Lynch, 1985). The name refers to how these scholars turned their attention away from 'nature' (associated with natural science) or 'society' (associated with social science), and instead observed how scientific work was carried out inside laboratories. Based on studies of scientific work and engineering practices, a scientific interest rose with the name 'science and technology studies' and abbreviated STS. The assumption in these studies is that developments in science and technology are subject to the same kind of dynamics. In the sociology of associations, scholars have their specific take on how these dynamics play out. The approach stems from social science but draws scholars' attention towards science and technology instead of only focusing on society and social relations.

This thesis contributes to an increasing body of literature that addresses building design practices from the sociology of associations (e.g. Harty, 2008; Houdart, 2008; Tryggestad et al., 2010; Yaneva, 2009). These studies aim to unpack design practices and understand their dynamics (Storni, 2012, p. 109). In the same manner, this thesis unravels design processes concerning a particular energy renovation project with the intention of understanding the dynamics in which energy become knowable and actionable for the designers. Drawing on the sociology of associations to such a quest implies following a vast set of heterogeneous and interconnected practices (Storni, 2012) which allow the energy renovation project to come 'into being'. From this perspective, a design is an outcome of emergent relations between elements, and it is through analysis of these relations that we can find out how design is made into being.

Many scholars of associations focus on how design is made ‘into being’, or assembled ‘in-the-making’, which points to an interest in the emergence of design (e.g. Storni, 2012; Yaneva, 2009). This study provides insight into how energy emerges in the midst of the design practices of architects, engineers, construction architects, as well as drawings, documents and other material objects. ANT analysis of design draws scholars’ attention towards the movements and transformations which lie behind products and artefacts (Storni, 2012), such as building designs. These movements and transformations are important to understand how building designs become as they become. Scholars also suggest to draw attention towards the ‘micropolitics of design’ (Schmidt et al., 2012) and the ‘seamless web of sociodesign’ (Fallan, 2008) where distinctions between technical, social, economic, and political become useless, and instead suggest to follow relations between human and nonhuman actors. This study contributes to these research efforts by focusing on how actors ‘assemble the social’ (Latour, 2005) through design processes.

The interest in design and design practices from an associations approach is not new, since some of the first sociology of associations studies shed light on the making of technological objects such as an electric vehicle (Callon, 1986c), the diesel engine (Latour, 1987), a military airplane (Law, 2002; Law & Callon, 1992), a photoelectric lighting kit (Akrich, 1992), and an automated train system (Latour, 1996). Based on studies of developments within science and technology, these studies go ‘beyond the boundary of the social in order to grasp natural and material objects’ (Latour, 2000, p. 108). Since then many authors have taken up the associations approach and investigated building design processes. Callon (1996) calls for more attention to architectural practices, which, among others, Yaneva (2005) and Houdart (2008) have taken up. As described in the previous chapter, many scholars have followed in the footsteps of Latour, Callon, Law and the others and shed light on the assemblies happening during building design processes (e.g. Harty & Tryggestad, 2015; Rydin, 2012; Tryggestad & Georg, 2011). This thesis finds inspiration in all these studies to explore how the design of an energy renovation happens ‘in-the-making’ and in this way follow Latour’s (1987) suggestion to follow, in this case, design, ‘in action’ instead of the ‘ready-made’ version of the design.

The research objective of this thesis is to study how designers make energy knowable and actionable during design processes. According to this purpose, drawing on the vocabulary of the sociology of associations seems to be useful, since this research tradition arises from a research interest in how scientists know the things they know (Latour & Woolgar, 1979). In the attempt to unpack the knowledge production processes of scientists, Latour and others developed a vocabulary to help them analyse and explain how scientific facts and technological artefacts become ‘accepted’, regarded as ‘truth’, or gain prevalence. Through ethnomethodological investigations of laboratories as well as research and development departments, ANT scholars examine the detailed actions made by scientists and developers and how their facts and artefacts become known. This thesis takes the same kind of interest in the knowledge production, and how facts and artefacts become knowable, however, in this case, the offices of building designers replace the laboratory. This thesis focuses on how energy as a phenomenon emerging from the knowledge production of designers and how different conceptualisations of energy performance may stand 'trials of strength'. Furthermore, the study follows Kurokawa, Schweber & Hughes (2017) in the point that knowledge cannot be treated as independent of the people and the objects that produce it (p. 921). In this way, the thesis follows 'the making' of an energy renovation project with all the 'political' disputes, 'controversies' and 'actors' such a process may entail. The subsequent section describes the analytical concepts which inform the analysis.

ANALYTICAL CONCEPTS

The founding fathers of the sociology of associations (e.g. Callon, 1986b; Latour, 1987; Law, 1992) argue that approaching science and technology studies from this stance necessitates the formation of a vocabulary suitable for studying hybrid actors and accomplishments of power relations. The purpose of the vocabulary is to dissolve distinctions between human and nonhuman actors, at least analytically, until the performances of the actors reveal their identity. In this way, they intend to avoid forcing any a priori definitions upon the actors. Since associations studies originate from an interest in how scientists and engineers construct scientific facts and technological innovations, the vocabulary aims to shed light on the processes involved when statements become 'true' and things become 'innovations.' Such processes include making something, like a scientific inquiry or an idea for a technology, knowable, and as an effect, actionable. The present thesis draws on the vocabulary to explore how building professionals make energy knowable and actionable during design processes. The thesis, therefore, assumes that similar processes as in scientific and engineering work occur in building design processes, and specifically, in energy renovation projects.

A crucial contribution in the vocabulary is the attention towards the practical, the mundane, and the detailed actions of practitioners. Latour (1986) draws attention to the material and mundane craftmanship of writing and imaging which are *"so practical, so modest, so pervasive, so close to the hands and the eyes that they escape attention"* (p. 3). It is in the specific interaction among actors that we find the construction of knowledge. He continues and suggests to follow the *"simple modifications in the way in which groups of people argue with one another using paper, signs, prints and diagrams"* (*ibid.*, p. 3). This statement highlights the importance of studying the interaction between people and their use of material objects as well as the possible disputes and discussions to which such interaction might lead. This thesis illustrates such interactions and discussions with a particular focus on how paper, printouts, and other nonhumans interact with the designers. The vocabulary provides focus on the practical achievements of writing and imaging to gain knowledge oneself or to persuade others about a statement. Knowing starts in the immediate interaction between 'hands and eyes.'

According to Law (1992), scientific knowledge is embodied in material form and is the end product of much hard work involving 'heterogeneous bits and pieces' juxtaposed into patterned networks which overcome resistance, a so-called process of 'heterogeneous engineering' (p. 381). Before statements can become knowledge, or in this case, a low-energy design can become known, much arduous work have to be done, and many heterogeneous bits and pieces must be arranged (and re-arranged) to form relations which are strong enough to endure over time. The word 'heterogeneous' illustrates the strength of the vocabulary to cross distinctions between human and nonhuman actors because the word highlights the multiplicity of actors. Actors are 'hybrids' (Callon & Law, 1995) that consist of both human and nonhuman actors. Actors are better illustrated as 'chains of human and nonhuman actors' (Latour, 1991, p. 110) rather than separate and distinct identities.

Latour (1987) studies the work of scientists in their laboratories and in their struggles of getting funding for research. Based on his study, scientists know about their object of inquiry and explain others about their findings through engagements with 'inscriptions.' Inscriptions are any visual display which has been extracted from the scientific work, been cleaned, redrawn and displayed in scientific texts (*ibid.*, p. 65). This thesis draws on the concept of an inscription, but instead regards inscriptions as any visual display in drawings or documents which similarly has been extracted from the work of the designers, cleaned to only depict particular phenomena, and redrawn based on previous design work. In this way, the thesis agrees with Whyte, Tryggestad & Comi (2016) that drawings show signs of previous work, however, the notion of inscription highlights that the work is 'cleaned', 'redrawn' and 'displayed' in a particular way.

Latour (1986) emphasises that inscriptions have the competence of acting as 'immutable mobiles.' Inscriptions are mobile because they can easily be moved. Not all scientific inquiry allows the object of study to be moved, like studies of planets or microbes, however, Latour argues, pictures of planets and Petri dishes can be moved. Inscriptions are immutable because when they move they remain the same even if they are moved through time and space, or at least, everything is done to obtain that result (*ibid.*, p. 19). A great amount of design work deals with inscriptions such as drawings, sketches, renderings, figures, and tables and they are important means for the designers to know aspects of the building design. At times, these inscriptions remain the same when they are shared among designers or are placed on tables and in folders for storage. Immutable mobiles also can be combined at will, making it possible for scientists to gather many types of information next to each other. Another characteristic of inscriptions is its ability to 'present absent things' (Latour, 1986, p. 8). Latour describes it as a 'two-way connection' between what is represented (e.g. planets) and the inscription (e.g. the picture of a planet). The 'absent thing' can also be an immaterial phenomenon such as an abstract imagining of a building design.

Even though Latour (1986) emphasises the advantages of inscriptions in the construction of scientific facts, he also highlights the importance of processes of mobilisation together with the circulation of inscriptions. To paraphrase Latour: inscriptions alone are worthless if they do not become part of mobilisation processes, and mobilisation processes are difficult without inscriptions (*ibid.*, p. 16). That is why studying the use of inscriptions is of vital importance, because it is in the mobilisation that inscriptions may modify the rhetoric of debate. Inscriptions give actors the ability to convince others about a statement:

> *"It is, first of all, the unique advantage they give in the rhetorical or polemical situation. 'You doubt what I say? I will show you.' And, without moving more than a few inches, I unfold in front of your eyes figures, diagrams, plates, texts, silhouettes, and then and there present things that are far away and with which some sort of two-way connection has now been established. I do not think the importance of this simple mechanism can be overestimated." (Latour, 1986, p. 13)*

Latour argues that if we want to study the construction of scientific facts, we should not only study inscriptions but instead follow "the cascade of ever simplified inscriptions that allow harder facts to be produced at greater cost" (*ibid.*, p. 16). This thesis regards arguments about building design features to go through similar processes of mobilisation where inscriptions play a vital role. This thesis draws on the concept of inscription to show how designers come to know aspects of the building design and how the presentation of inscriptions influences the designers' ability to convince one another about the 'truth' of their statement.

Inscriptions not only 'present absent things,' but they also hold these 'things' in place. According to Latour (1991), "nonhumans offer the possibility of holding society together as a durable whole" (p. 103). Many different nonhumans participate in such actions, for example, machines, organisations and belief, however, inscriptions also make the society, or the work of scientists as well as designers, durable across time. As nonhumans, inscriptions act as 'lieutenants' (Latour, 1988, p. 308) holding the place of or for someone else through the delegation of competence. For example, drawings can save details about design features over time and re-present the details over and over again at different occasions. If scientists lack inscriptions, their knowledge about their object of inquiry starts to become wobbly:

> *"When these resources were lacking, the self-same scientists stuttered, hesitated, and talked nonsense, and displayed every kind of political or cultural bias. Although their minds, their scientific methods, their paradigms, their world-views and their cultures were still present, their conversation could not keep them in their proper place. However, inscriptions or the practice of inscribing could." (Latour, 1986, p. 4)*

Inscriptions enable scientists and, as this thesis argues, designers to make their inquiry 'more durable' by holding it, or at least parts of it, 'in place.' In this way, inscriptions contribute to the stability of statements concerning both scientific claims and claims about design features.

The sociology of associations both propose the term inscriptions for material objects, as described above, but also the process of 'inscribing' (Akrich, 1992). Akrich describes how designers make material objects and how users use the designed objects. According to her, designers transform their "vision of (and prediction about) the world" (*ibid.*, p. 208) into material objects in the process of inscribing. When the material objects then become used, Akrich suggests the term 'de-scription' as the process of 'reading' the intentions of the technical objects. Depending on how the material object is being used, the user might 'subscribe' to what has been envisioned by the designers by doing as they predicted, or 'de-inscribe' to their visions by going against the "purposes" of the design (Akrich & Latour, 1992). In this thesis, the analytical concepts of inscription, description, subscription and de-inscription are all used to show how intentions are transformed into material objects and whether if the intended users follow these intentions.

Because inscriptions are 'immutable and combinable mobiles' (Latour, 1987, p. 227), they allow actors to 'act at a distance' on unfamiliar events, places and people by bringing these events, places and people to who only 'see it for the first time.' To know about it in this sense is to be familiar with things, people, and events, which are distant (*ibid.*, p. 220). In their ability to 'present absent things,' inscriptions can display phenomena as shores of distant lands in maps which then can be manipulated by people who are not standing at these shores. Because the inscriptions provide the two-way connection between 'here' and 'there,' the presences of 'there' is brought into 'here.' Moreover, it does not matter whether 'there' is figurative such as gods, myths, or abstract phenomena, like 'organisations,' or it can also be tangible, like machines and people. By circulation of inscriptions, actors can 'act on a distance' by mediating interests through inscriptions. Whether these interests prevail, however, is another question which depends on processes of mobilisation.

Processes of 'mobilisation' involve what Latour (1986) calls the 'mustering of allies.' When people try to convince one another about something, the mustering of allies happens when people refer to actors and speak on their behalf. For example, the sentence 'the Government has introduced new legislation on energy performance; therefore, we need to introduce more energy renovations' illustrates the mobilisation of 'the Government' and their 'legislation' as actors favouring 'more energy renovations.' The speaker speaks on behalf of the Government and the legislative documents to encourage others to follow his interest in energy renovations. Although the mobilisation of actors may seem stable, Callon (1986b) argues that this is not always the case. According to him, actors may 'betray' attempts to mobilise. He describes how three marine biologists attempt to mobilise fishers, a research community, and even scallops in their research project (*ibid.*). To get the attention of the other actors, the biologists devise a research program where they place themselves as an 'obligatory passage point.' In other words, if the fishermen will earn more money by collecting more scallops, the research community learn more about how scallops reproduce, and the scallops want to multiply in numbers, then the three groups have to follow the biologists in their proposed research efforts. The biologists describe the research program as if the three other groups have no other choice than to follow their suggestions. The biologists obtain the acceptance of the other three groups and the research project progresses. Callon (1986) describes that the scallops betray the other actors and do not reproduce as expected. The fishermen also betray the research project and collect scallops too early, because they want short-term profits instead of waiting for the scallops to multiply. The example described by Callon (1986) illustrates how actors may be 'enrolled' into specific agendas, but also that mobilisation is not certain and might lead to betrayal. This thesis draws on the concepts of enrolment, mobilisation, obligatory passage point, and betrayal to show how actors attempt to further one's interests and how other actors may or may not follow these interests.

The process of mobilisation described by Callon (1986) is also called a 'process of translation.' Translation is when actors define the identity of other actors, and hence, their interests. Translation involves a translator, something that is translated, and a medium in which that translation is inscribed (Callon, 1991, p. 143). Callon (1991) suggests four types of intermediaries that can support translations, namely texts, technical objects, skills, and money. To translate an actor, other actors inscribe definitions of these actors and their interests into intermediaries. However, whether the actors decide to embrace the definition or reject it is never certain and depends on the actions of these actors. Attempts to define other actors, that is attempts to translate, can result in controversies, conflicts and the attempt can become a 'betrayal' (Callon, 1991, p. 144). If actors, on the other hand, decide to embrace the definition, translation processes can create 'alignments' between actors. When actors align, their interests are consistent. According to Latour (1988), translation may also be the replacement of a human action with the action of nonhumans. He calls such replacement for the 'delegation' of work or the 'displacement' of competences. Translation in this sense resembles the concept of 'inscription' since it is the transformation of ideas and interests into material form. Latour (1988) argues that scripts can become more durable by translation into nonhuman (p. 306). This thesis draws on the notion of translation as the definition of other actors' interests and the transformation of interests into material form (i.e. inscription).

Latour (1991) gives a similar description of how actors might encourage others to follow their interests. In an example describing a hotel manager attempt to get his guests to return their hotel keys to the reception, Latour (1991) introduce the concepts of 'program of action' and 'anti-program.' The concepts take their starting point in one actor which in this case is the hotel manager. He wants his guests to leave their keys at the reception, and he makes a range of actions to obtain this result. The actions are the program of action. The hotel manager arranges a written sign which asks guests to leave their keys, he attaches heavy objects in the key chains, and he asks them in person to return the keys. All these actions are his 'program of action' – his attempts to convince the guests to do as he says. However, guests may behave otherwise by forgetting their keys, ignoring the written sign, or disobey the order from the hotel manager. All these actions are 'anti-programs' because they go against the interests of the hotel manager. When experiencing anti-programs, actors may 'load' their program (Latour, 1991). In this way, they strengthen their program of action by making yet new actions to prevent anti-programs. This thesis draws on the dynamic between programs of action and anti-programs to show how tensions between interests play out in the actions of the designers.

When conflicts between competing interests occur, Latour (1987) calls these for 'trials of strength.' The trial shows how actors impose interests on each other in attempts to make others follow their interests. The effect of trials of strength is the success of one set of interests and the downfall of another. According to Latour (1986), the one who can muster the most allies wins the trials. The concept of trials of strength is an example of how actors compete about specific interests – in the same manner as illustrated with the other concepts described above. This thesis draws on the concept of trials of strength to highlight tensions between opposing, conflicting, and competing interests.

All the analytical concepts mentioned above originate from the sociology of associations literature. However, the literature on building design processes also offers analytical concepts which explore how design features are made knowable and actionable. According to Whyte, Ewenstein, Hales & Tidd (2007), material objects may be treated as either frozen or fluid by designers. When treated as 'frozen,' drawings are regarded as unavailable for change, and when treated as 'fluid,' drawings are regarded as open and dynamic (*ibid.*, p. 18). In this way, designers might regard parts of a drawing for fluid and other parts for frozen, or perhaps sets of drawings for frozen and sets of drawings for fluid. It all depends on the design interaction. Whyte et al. (2007) continue their concept of frozen by introducing processes of 'freezing,' 'unfreezing' and 'refreezing' (pp. 19-20). Through these processes, designers stabilise design features by freezing them in drawings or other material objects. However, designers are also able to unfreeze design features which were earlier regarded as frozen in order to discuss them again and perhaps refreeze them in material objects. In this way, the concepts of frozen and fluid allow analysis of design interactions which stabilise design features and open up already stabilised or yet-to-be-questioned design features.

Based on a reflection of Latour's (1986) notion of immutable mobiles, Ewenstein & Whyte (2009) argue that drawings are treated as 'immutable' in their case, but instead, drawings are essentially 'mutable' in the way they change, unfold and evolve during design processes (p. 27). Continuing the argument from Whyte et al. (2007), this thesis regards Ewenstein & Whyte's (2009) argument for valid, since material objects may be regarded as both immutable and mutable depending on the situation. This thesis considers the question of whether material objects are treated as immutable or mutable for an empirical question and a discussion concerning how designers act with material objects in a given situation. Ewenstein & Whyte (2009) also suggest that some objects, which they call 'technical objects,' may be treated as given and become 'reference points' during design interactions (p. 27). This thesis considers the possibility that material objects can be used as 'reference points' and treated as temporarily stable and given.

Continuing the discussion on stabilisation, Whyte, Tryggestad & Comi (2016) argue that design work, or what they call 'paper-work' and 'model-work', is central to producing 'cascades of visual representations.' According to them, cascades of visual representations enable stabilisation and fixing of images of the design (*ibid.*, p. 118). In their study, they observe how multiple sets of texts, pictures, and notations create connections forming cascades of visual representations (*ibid.*, p. 126). The cascades of material objects stabilise building designs by fixing multiple views of the building design in multiple different objects. Kurokawa, Schweber & Hughes (2017) make a similar argument where they state that 'overlays of devices' or 'myriads of devices' contribute to the durability or inflexibility of particular design features (p. 921). According to Kurokawa et al. (2017), material objects fix particular details, and when an increasing number of design features gets fixed, some design features can be considered as 'non-negotiable' (p. 923). Based on such observations, material objects have a role in stabilising design features and making them more durable. This thesis considers the role of material objects in both their contribution to fix, stabilise, and freeze design features as well as open up, make fluid, and unfreeze design features.

The thesis draws on the abovementioned analytical concepts and insights to study how energy is made knowable and actionable in an energy renovation project. In doing so, the thesis focuses on how designers circulate inscriptions among themselves in the course of negotiations in attempts to define energy-saving design features. Furthermore, the processes with which the designers inscribe certain interests into material objects is examined to follow the designers' attempt to further their interests. This thesis is inspired by the concepts of enrolment and mobilisation to investigate how the designers attempt to enrol and mobilise others in their interests. In this way, the thesis focuses on trials of strength between different interests and how designers translate interests during negotiations. Lastly, this thesis focuses on how interactions between designers and material objects stabilise, or freeze, design features in some moments, while in other moments, interactions between designers and material objects open up and unfreeze other design features.

The study builds on ethnographic research methods to gain insights into dynamics involving negotiations of interests and use of material objects. These research methods are described in the next section.

ETHNOGRAPHIC RESEARCH METHODS

The present study focuses on the accomplishment of an 'energy-efficient design' as it occurs 'in the making.' A methodological implication of this research interest is attention towards the actions and the associations made by actors in the course of a building design project. With the aim of exploring how designers make energy knowable and actionable in practice, the study draws on ethnographic methods such as observations and interviews. Ethnographic methods have gained significant attention in the construction industry over the last decade (e.g. Pink, Tutt, Dainty, & Gibb, 2010; Schmidt et al., 2012; Yaneva, 2009), and this study contributes to this work by reporting on the study of an energy renovation. With ethnographic methods, scholars gain access to the 'doings' and 'sayings' of practitioners and get close to the work they perform. In this way, the study aims at getting insights into the detailed interactions between designers and material objects. A small view into the 'machine room' of design processes involved in an energy renovation project.

Ethnographic methods are developed within social science and usually involve spending extended periods of time with the people who one is researching, observing behaviours, writing extensive notes, interviewing, and reflecting on one's role in the research process (Pink et al., 2010, p. 648). As a result, ethnographic methods are often referred to as being demanding, time-consuming, and typically involves considerable efforts in analysing the empirical material during and after observations have been conducted. According to Pink, Tutt, Dainty & Gibb (2010), it is not possible to undertake theory-free ethnography, and the researcher should retain reflexive awareness of how theory and practice remain in dialogue throughout the ethnographic process (p. 649). Correspondingly, this research is inspired by studies of building design which take a sociology of associations approach to their research, and this study aims to follow designers in their everyday, mundane practices and their interactions with material objects, since such an approach can provide insight into how the designers make energy-saving design features knowable and actionable. Reflexivity has been provided in the study by several analytical discussions with research colleagues after the fieldwork was carried out. The many analytical discussions have led to different interpretations of the empirical material (a few of them are shown in the Appendix).

The sociology of associations is an approach with strong methodological implications (Latour, 1999). The most basic statement about research method, and perhaps the greatest challenge of them all, is the suggestion to "follow the actors" (Latour, 2005).

What this statement implies is that scholars should travel light (with notebooks and recording units) in order to move along any associations that the actors they study make during their research. That is, to trace the unfolding relations that are relevant for the particular research objective within the time and resources available to the researcher. Practically speaking, this is close to impossible, because of the infinite number of relations which make up real-world situations. However, the suggestion of 'following the actors' may also imply to trace any actions made relevant to the object of study, observed by the researcher, and the relations they constitute. By focusing on actions made concerning 'energy performance', this study delimits the research object to associations related to energy. Other associations, without any link to energy performance, is not relevant for the study. In this way, researchers can focus on and follow any relevant actions made concerning their object of study, document them and analyse them. The present study builds on such a philosophy, namely if any actor, human or nonhuman, acts during the study and this action is related to the object of study, then the action becomes relevant for the analysis.

Taking an associations approach to the study of building design means to abstain from making any 'a priori' judgements about how design 'is' and not to make any prior categorisations of the involved actors. It is the actors themselves who define how they believe the world works and their theories of what design 'is' that is important. Scholars must try to leave any pre-established definitions and instead follow the actors and through these observations gain access to the actors' definitions of 'the social' (Yaneva, 2009, p. 24). In this sense, the study does not try to illustrate what would be the 'best' way to account for energy performance during renovation projects or depict the empirical case as a 'best practice' example. The aim is to trace the associations made by the actors and how they make 'energy performance' knowable and actionable as they work on a specific building design.

The study focuses on actions as they are situated in practice. In other words, the study follows what Lucy Suchman (2007) calls 'situated actions.' According to her, every course of action depends on essential ways upon its material and social circumstances (*ibid.*, p. 50). From this point of view, the study locates action in specific circumstances and investigates how designers use these circumstances to make purposeful actions. Continuing the notion of 'situated action' presented by Suchman, this study examines by which methods that material objects and actions are made significant in particular, concrete circumstances (*ibid.*, p. 50). The following sections describe how the study has gained insight into the situated actions of designers and material objects.

This study draws on qualitative research methods of observation and interviews. Interviews provide reflections from designers about what has happened in the energy renovation project and how they have dealt with energy performance issues. Observations provide insights into the detailed interactions among designers and material objects in which particular energy concerns emerge. As a supplement to the two methods, the study also lets nonhumans 'speak' by tracing statements made in crucial documents and constellations of drawings, text and figures. The overall aim has been to disturb the designers and their work as little as possible by observing work in practice and then asking questions later in follow-up interviews (see for example Pink et al., 2010, p. 649). However, interference is unavoidable, and the mere presence of the researcher may have caused the designers to react differently. Even so, the analysis is based on the actions observed and the statements made by the designers, no matter the interference from the researcher. The ethnographic study was conducted for just about a year from August 2015 until June 2016. During this time period, the renovation project moved, according to the project participants, from 'conceptual design' (January to September 2015), over to the 'application for building permit' (September to November 2015), and to 'main project design' (December 2015 to June 2016), where the project was put to 'tender' in June 2016. Two interviews were done during the first half year (August 2015 to February 2016), video recordings were made of nine design meetings during two months (April and May 2016), and six follow-up interviews were made during the last half year (June 2016 to January 2017).

The following three sections describe how fieldwork has been conducted based on video recordings, interviews, and review of project documents respectively.

VIDEO RECORDINGS OF DESIGN MEETINGS

Video recording as a research method provides vast amounts of rich and detailed audio-visual data. Video recordings allow one to capture interactions as they happen in specific situations and enable analysis of these interactions in many ways. Video allows researchers to record naturally occurring activities as they arise in ordinary habitats, such as the workplace (Heath, Hindmarch, & Luff, 2010). In this case, the workplace in focus in this study is the offices of the designers. The aim of using video recordings is to get detailed documentation of the tasks that actors perform as they usually do, with minimal disturbance from the researcher. However, video recording will always be an obtrusive research method, and there is, therefore, no 'free ride' in the social world (Czarniawska, 2014, p. 36). However, the recordings of real-time activities document talk, visible conduct (such as gaze, gesture and facial expression), as well as the use of material objects (Heath et al., 2010), and in this way to trace associations between human and nonhuman actors. The purpose of the video recordings is to document how designers use material objects during negotiations concerning energy-saving design features. During data analysis, videos allow one to recapture the situated actions over and over again to study particular details of the actions.

The video recordings were made during design meetings. This is where the designers meet to discuss the status of the renovation project and deal with any significant issues or concerns that could influence the project. Designers bring material objects to the meetings to support their discussions about building design's specificities, and it is at these meetings the designers bring up important issues relating to the project. They do so explicitly, so other team members can understand the issue and in collaboration decide what to do with the issue. These meetings are therefore important sites for developing the designs, and they provided access to the designers' ideas, understandings and concerns about energy-saving design features. Because the design meetings were recurring events, video recordings could be anticipated. Activities that were taking place in between the meetings were documented by interviews and document analysis (see below). The design meetings were held in meeting rooms within the same company (see Chapter 4, The Case). Video recordings were conducted in a period of two months from April to May 2016. A total of nine meetings were recorded. Issues about energy performance were brought up by the designers at seven of these meetings (amounting to nine hours and seven minutes of video recording), while energy-related issues were not discussed at the two other meetings (one hour and 25 minutes of video recording). During all of the meetings, only employees affiliated at the renovation project and employed by the company were present. The number of meeting participants varied from meeting to meeting, but the project manager, a few architects, a few construction architects, and a few engineers with a speciality in HVAC, plumbing, and construction were present at most of the meetings. Before each meeting, the participants gave their verbal consent to allow the meeting to be recorded.

The design meetings were recorded with a camcorder (a small, hand-held video camera with a microphone on the side) which allowed movements around the room as well as zooming into meticulous interaction. Most of the time, the camera was held in a stationary position to allow for direct, nonparticipant observation (Czarniawska, 2014, p. 44). The stationary position was either in the corner of the room or from a chair where the camera angle imitates the point of view of an extra meeting participant. The framing of the camera depended on the actions of the meeting participants. During verbal discussions where the participants made only gaze, facial expressions, and gestures, the camera included (or the attempt was made to include) every meeting participant in the frame. The purpose of this was to ensure that if a meeting participant suddenly reacted to a statement, the video could still record the reaction. During close-up interactions between designers and material objects, for example, during sketching, the camera frame focused on the activity of the designers by zooming into what is being done to the material object. This sometimes required the observer to stand up and move around in the meeting room in order to record what the designers were doing. The movement between large frames (including all participants) and close-up frames (including typically hands, pens and sketching activity) provides both data on verbal discussions and detailed design activity. Video recording always involves a compromise between encompassing participation and accessing the details of conduct (Heath et al., 2010). In this study, the details of conduct relating to for example sketching activities trump the attempt to encompass participation from all meeting participants.

No matter what one does, video recording actions involve selecting what to record, how to record it, and which equipment one uses. All these choices have an impact on the data one can use in subsequent analysis (Heath et al., 2010). In this case, the camera frame sometimes meant that actions became blurry, or objects or people stand in the way of an activity, or sounds interfere with the recording of people's voices, or actions were made before the camera was not turned on or after it was turned off. All these situations may arise and have occurred while conducting the video recordings for this study. Such situations are, of course, not included in the analysis, since they are not documented through the fieldwork. Since the analysis focus on significant discussions or 'controversies,' brief moments of technical disturbance or blocking of view/hearing do not change the status of the debates happen across several situations.

The video recordings are transferred to a Qualitative Data Analysis (QDA) software together with other types of empirical material from the study. The software can play videos and code videos concerning analytical concepts. Description of data processing can be found further down.

INTERVIEWS WITH DESIGNERS

Although the video recordings of design meetings give a rich and detailed picture of design interactions, they provide, however, rather brief insights into the project, compared to the whole lifetime of the project. Interviews provide insights into the negotiations and actions made by designers in the course of the design process as presented by the research participants. During the interviews, the designers are asked to reflect on their actions, how the processes have occurred during the project, and how the designers considered energy performance issues. The purpose of the interviews is to tie together the negotiations concerning energy performance to the general development of the project. At the same time, interviews give access to the designers' intentions about their actions. Social scientists are not able to access their research participants' thoughts, but they can ask them to tell stories about how they experience the world and previous actions. In this way, the analytical aim of the interviews is to provide descriptions of the political dimensions of the design processes and how different interests might conflict with each other. Interviews 'add one more meaning' (Czarniawska, 2014, p. 39) to the descriptions of how energy performance has been made knowable and designable, adding to the insights provided by the video recordings. Where video recordings give insights to what the designers do, the interviews provide descriptions of how the designers account for what they do and their interests (*ibid.*, p. 38).

Participants were recruited by contacting them by email or phone call and asking them if they wanted to participate in an interview about the renovation project in which they were involved. The first interview was conducted with the person who provided access to the renovation project, that is, the project manager from the building client consultancy company (called the 'client's manager' in Chapter 5 and 6). The interview was held in November 2015. The rest of the interviews were conducted with designers from the same company, the consultancy company responsible for delivering the detailed design of the renovation project (see Chapter 4, The Case). The first designer to be interviewed was the energy consultant from the design team. The interview was held in February 2016. The remaining six interviews were held after video recordings were conducted. The interviews were conducted from September 2016 to January 2017. The interviewees were: The project manager, two architects, a construction engineer, an HVAC engineer, and a plumbing engineer. All of these designers feature in the video recordings of the design meetings. By conducting the interviews after the video recordings, gave the opportunity to ask the participants to reflect on situations happening during the design meetings a few months earlier. In this way, the participants were able to explain why they did as they did and how they experienced the negotiations. At the end of each interview, each interviewee was asked if they had any questions for me and afterwards they gave their consent to the information being used as part of this research.

All the interviews were conducted at the interviewee's place of employment and the interviews lasted from about one to two hours. The questions asked at the interviews were based on interview guides involving questions about how the participants have dealt with the energy requirements at the project, how decisions regarding energy-saving initiatives were made, and how the participants experienced particular events observed by the researcher during the project. The interviews were audio recorded and saved as an audio file in a QDA software. The interviews were transcribed according to what the interviewees said, however without pauses, hesitations, or two statements in a row stating the same thing. In a few cases, statements were adjusted from spoken words to written text. Questions posed by the interviewer and answers provided by the interviewee were time-stamped according to how far in the interview the statements were made. The written transcripts were also transferred to the QDA software.

REVIEW OF DOCUMENTS & DRAWINGS

This study focuses on both human and nonhuman actors and includes a collection of documents, drawings and other types of project material from the renovation project. Notably, the documents and drawings which the designers refer to during the observations and interviews are considered crucial for the emergence of energy performance.

The project material was downloaded from an online file sharing system used by the designers to deliver project material to the building client organisation and saved on an external hard drive. The material consists of documents specifying technical design decisions, drawings of architectural and engineering design, as well as memos from meetings. When project participants mentioned a document or drawing concerning the design of low-energy performance, then these documents and drawings were read and analysed according to which associations they constitute. There were a few documents, which were repeatedly referred to and, therefore, also subject to more attention analytically than other documents; namely a document on energy requirements written by the energy consultant in the design team, a document specifying technical and economic specifications for ventilation systems, and the collection of drawings and texts which made up the design competition material. It was not possible to gain access to emails, digital document filing system, or the digital models of the project in the company.

The analytical aim of studying project material is to follow how these material objects act in certain ways as an effect of the associations they create – both read in them and how the project material circulates among other actors. Statements in the project material are therefore placed on the same footing as statements made by human actors (similarly as Kurokawa et al., 2017, p. 915). All the statements create associations which may affect how the project evolves. Scrutinising the project material is a way to 'follow the actors' and to what these actors associate.

The next section describes how the empirical material gathered through the fieldwork has been processed to reach the analysis in Chapter 5 and 6.

WORKING WITH THE EMPIRICAL MATERIAL

From the fieldwork, the empirical material consists of video clips, audio recordings, interview transcripts, photos, field notes, as well as drawings and documents from the renovation project. All the empirical material which not already was in English has been translated from Danish into English. In this way, statements from research participants and written text from project documents have been translated into English. All the empirical material, except for the drawings and documents because of their size, was transferred to a Qualitative Data Analysis (QDA) software. In the software, annotations were made to audio and text when the designers mentioned or referred to design issues or proposed solutions related to energy performance. The identification of design interaction related to energy performance was made based on four criteria found from research. First, when the designers mentioned any specifications relating to the thermal envelopes of the buildings. Insulating the thermal envelope of buildings improves the energy performance of the buildings (e.g. Sadineni, Madala, & Boehm, 2011). Second, when designers mentioned the replacement or maintenance of technical installations that have an effect on energy consumption. Among such installations, research especially highlight mechanical ventilation systems with heat recovery, replacement of boilers for domestic hot water, solar panels, and photovoltaics as examples (e.g. Morelli et al., 2012). Third, if the designers mentioned renewable energy sources, such as photovoltaics (e.g. Chwieduk, 2003). Fourth, when designers mentioned occupants, occupant behaviour, or occupancy in general and related this information to energy consumption. Much research highlights that occupant behaviour influence energy consumption in buildings (e.g. Guerra Santin, Itard, & Visscher, 2009). These four criteria have been the outset from which the empirical material has been analysed.

Based on the four criteria, numerous design situations, statements from the designers and statements in texts were identified. Inspired by the sociology of associations, the analysis focuses on how these situations and statements 'act' or have an effect in the design process and the making of the energy renovation project. Accordingly, isolated instances of statements or information that have not been taken up later in the process or do not stand against any other statements or information have been discarded. Only situations in which the designers handle issues of energy-saving design features and negotiate these issues have been included. Out of the many instances where the designers negotiate design features that relate energy performance (based on the four criteria), five instances have been presented by the designers as 'problematic' and 'worth of attention.' The five instances involve negotiations around the following topics, presented in chronological order as they appear in the design process:

- The choice of the ventilation system with heat recovery
- The re-specification of energy requirements based on previous specifications
- The thermal insulation of joints between building components to prevent thermal bridges
- The thermal insulation of basements
- The thermal insulation to prevent floor heating in heating downwards

Whereas many design issues related to energy performance only took up the attention of the designers shortly, these five issues recurred over several design meetings and involved prolonged negotiations among the designers. The five 'problematic' design issues are interesting because they show how the designers make the design problems knowable through different actions and how they make the problems actionable by suggesting solutions to solve them. The five design issues are divided into two analytical chapters, namely Chapter 5 and 6. Chapter 5 focuses on how the designers make the issues and solutions knowable and actionable through negotiations. The chapter illustrates how the designers attempt to persuade each other to follow particular suggestions and how these attempts develop into negotiations of interests and ultimately trials of strength. The chapter illustrates energy performance as a matter of competing concerns and a need for designers to enrol allies if they wish to achieve certain interests. Chapter 5 elaborates on the design issues concerning the ventilation system and the energy requirements.

Chapter 6 focuses on how the designers engage with material objects to make the issues and associated solutions knowable and actionable. The chapter shows how the designers involve themselves in recursive design interactions with material objects in order to solve the specific problems. The chapter illustrates how material objects help the designers discover unexpected issues, solve issues, and stabilise particular design features. Chapter 6 elaborates on the design issues concerning thermal bridges, thermal insulation of the basements and the thermal insulation to prevent floor heating in heating downwards. Even if Chapter 5 and 6 foreground negotiations and material objects respectively, both chapters illustrate the design of the energy renovation as involving repeated negotiations and the omnipresence of material objects in design work.

The interaction illustrated in the analysis taken from video recordings are excerpts from hour-long meetings. Sequences of interaction are included when the designers either discover new insights into the design problem, propose solutions to the other designers, or negotiate the issues with other designers. In this way, the analysis shows how the five issues are made, develop over the course of the design process, and are resolved (if this is the case). Sequences of interaction from video recordings are transcribed according to a conversation analysis method (Hyysalo, 2010, p. 113). The conversation analysis notation is modified and is used in the following way:

> () marks a pause without specifying the length
> ((*text in italics*)) is used to mark action and objects when speech and action fully intertwine
> ((text)) is used to clarify what is denoted in expressions or Danish wordplay

Conversation analysis notation accompanied by screenshots from the video recordings re-present the moments where the designers negotiate the issues. This way of presenting the sequences of interaction illustrates both how the designers negotiate the topics and how they engage with material objects as they negotiate the topics.

Based on the ethnographic research methods described in this chapter, Chapter 5 and 6 unfold the five issues concerning energy-saving design features in five 'empirical stories.' According to Eidenskog (2017), 'empirical stories' allow researchers to carefully slow down and keep attention on minute interactions between humans and nonhumans. By carefully slowing down, Chapter 5 and 6 present how the designers make energy-saving design features knowable and actionable through their everyday design practices.

The next chapter presents the case of this study which involves an 'ambitious' and 'comprehensive' energy renovation of four multi-family apartment buildings.

CHAPTER 4 The Case

The Case

4 Case

THE ENERGY GOALS IN AN 'AMBITIOUS' RENOVATION

The project manager from the client organisation characterises the energy renovation project as an 'ambitious' and 'comprehensive' energy renovation. The project manager regards the energy renovation project as ambitious because the project aims to achieve the energy performance required for new buildings in existing buildings. Energy requirements for new buildings in the Danish building code are stricter than the requirements for renovations. The project manager considers the project to be comprehensive because it consists of several renovation initiatives where energy-saving initiatives are only a few of them. The energy renovation project involves modernisation of kitchens and bathrooms, merging of apartments into larger apartments, restoration of green areas around the buildings, new balconies which provide step-free access to apartments via lifts, new apartments, and the buildings get a new architectural expression. Concerning energy performance, the project involves new highly-insulated facades and gables with new windows and doors; highly-insulated roofs; a new heating system including heating boilers, radiators, and heating pipes; new mechanical ventilation system with heat recovery; and new electrical installations and fixtures. The aim of the energy renovation is, according to the project manager, to remedy a poor reputation which the buildings have in public. According to the project manager, the buildings are nearly becoming a 'ghetto' because of a high rate of unemployment and a uniform resident composition. Renovations may contribute to make buildings more attractive and minimise possible 'ghettoisation' (the Danish Association of Construction Clients & the Landowners' Investment Foundation, 2011, p. 32). The project manager and client organisation want to avoid this tendency and encourage families with young children to live in the buildings because they regard such families as being the core in 'well-functioning' housing areas. Lastly, however not least, the project manager and the client organisation want to increase the indoor comfort for the residents and lower their energy bills through the energy renovation.

The energy performance goals of the project are to achieve 'energy class 2015' and 'energy class 2020' as described in the Danish building code (the Danish Transport Construction and Housing Agency, 2019). These energy classes are requirements for new buildings. The two energy classes were introduced together with the new building code in 2010 (the Danish Business & Construction Agency, 2010), at about the same time as the client organisation initiated the energy renovation project. The building code from 2010 replaced a building code from 2008. 1 January 2016, the Danish Government introduced yet another building code, called the building code 2015 (the Danish Transport and Construction Agency, 2015). The energy renovation project has to comply with the building code 2015, since the building client applies for building permit in January 2016 where the building code has just replaced the building code 2010. The energy classes are defined as ‘energy performance frameworks’ in the building code 2015, and based on calculation, the building client has to document that the buildings will not exceed a specific energy demand for heating, ventilation, cooling and domestic hot water. For the energy class 2015 the energy demand must not exceed 30 kWh/m^2 per year, plus 1,000 kWh/m^2 per year divided by the heated floor area of the building (DTCA, 2015, BC15, 7.2.2, sub-section 1). The same applies to the energy class 2020, however, to achieve this energy class, the energy demand of buildings may not exceed 20 kWh/m^2 per year (without any supplement, DTCA, 2015, BR15, 7.2.4.2, sub-section 1).

The reason why the project has to comply with both the energy class 2015 and the energy class 2020 is that the project is divided into two parts: A new building part and an existing building part. The project aims to renovate four existing multi-family apartments buildings. The buildings have four storeys and consist in total of 284 apartments, and they take up approximately 20,000 square metres. One of the apartment buildings is going to be extended with what corresponds to a staircase with associated apartments (see figure 4.1). On top of the four buildings, new ‘penthouse’ apartments are going to be constructed. In this way, the extension of one apartment block and the penthouse apartments make up the ‘new building part’ of the project. The rest makes up ‘the existing building part’ which is going to be renovated.

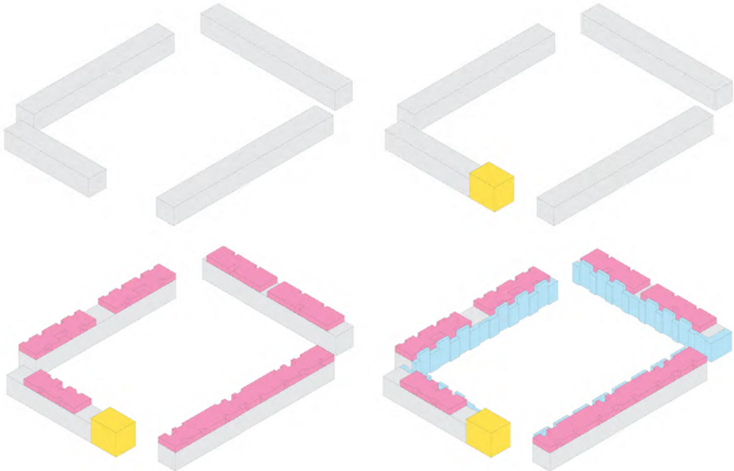

Figure 4.1: The figure shows four illustrations of how the existing buildings are planned to be renovated. The top left picture shows the four existing apartment buildings (the grey blocks). The top right picture shows how one of the apartment buildings are going to be extended with what corresponds to a staircase with associated apartments (the yellow block). The bottom left picture shows that on top of each of the four apartment buildings, there is going to be built new 'penthouse' apartments (the pink blocks). The bottom right picture shows how the four apartment buildings will get new balconies (the blue blocks) towards the inner garden. The grey and blue blocks represent the 'renovation part' of the project, while the pink and yellow blocks represent the 'new building part.' (The illustrations are made by the architectural company that designed the 'conceptual design' of the renovation project).

According to the building client, the energy renovation project must comply with energy class 2015 for the existing building part and energy class 2020 for the new building part. The building client requires the existing buildings to be renovated according to energy class 2015 in order to make it an 'ambitious' energy renovation. Concerning energy class 2020, the project manager states that the local authorities want all new buildings in the municipality to comply with one energy class higher than required in the current building code. In the building code 2015, new buildings have to comply with energy class 2015, so the 'new building part' of the project has to comply with energy class 2020 which is the next energy performance framework. According to the building client, the 'renovation part' constitutes approximately 80 %, and the 'new building part' constitutes approximately 20 % of the project.

The energy classes are defined as 30 + 1,000 kWh/m^2 per year and 20 kWh/m^2 per year respectively. The two requirements do not state how buildings should be designed to comply with the maximum of energy demand. Compliance can be achieved in endless ways as long as the resulting performance does not exceed the requirement. By describing performance-based energy requirements, the building code gives building professionals freedom to design the buildings as they want, but such requirements may also lead to uncertainty whether the requirements will be fulfilled or not by specific design choices. The energy classes are documented based on calculations, and building professionals need to make calculations to know if design choices are within or exceeding the requirements. If building professionals lack competences in energy calculations, they might not know how choices regarding design features influence the energy performance of the buildings. The requirements might guide the design of buildings, but they might also provide uncertainty among building professionals who do not have expertise in energy performance.

This research is inspired by the ambition of the building client to the achieve energy performance which is usually required for new buildings in a project dealing mostly with the renovation of existing buildings. Based on the energy requirements, the following questions initiated the present study: If the energy renovation project is deemed an 'ambitious' project, how do the designers then transform this ambition into specific and detailed project material? How do the designers deal with energy requirements such as the energy classes? Moreover, how do the designers treat issues concerning energy performance of the buildings? This thesis attempts to answer and reflect on such questions.

The next section presents the buildings and the role of the building client in more detail.

RENOVATING MULTI-FAMILY APARTMENT BUILDINGS

The energy renovation project comprises four multi-family apartment buildings. The buildings are built in the 1960s and are part of the approximately 140,000 dwellings constructed as multi-family apartment buildings in Denmark from 1960-1969 (Statistics Denmark, 2019). The buildings consist of prefabricated, standardised concrete elements and industrial-produced building components which was typical for the 'prefabricated construction era' of the 1960s and 1970s (Bech-Danielsen et al., 2011, p. 16, for examples of similar buildings see pages 93, 103, 117, and 173). The prefabricated constructions of the time were an attempt to 'rationalise' the building process and standardise building components into mass production for increased profit (*ibid.*, p. 23). However, the prefabricated construction led to the use of new materials, constructions and working methods which later revealed building faults, damages and a need for renovation of the buildings (the Danish City and Housing Ministry & the Danish Business Ministry, 2000, p. 81). The present case is an example of the many multi-family apartment buildings built in the era of prefabricated constructions and which renovations are needed because of damages to the building components. Figure 4.2 illustrates how the buildings are planned to be renovated.

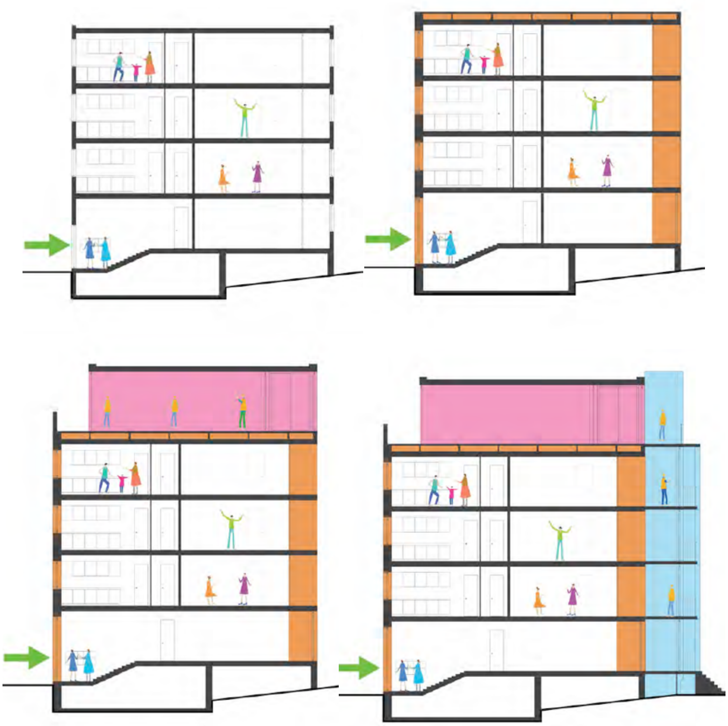

Figure 4.2: The figure illustrates how the buildings are planned to be renovated. The top left picture shows a section through one of the existing buildings. The top right picture shows how the designers will insulate the thermal envelope of the buildings. The bottom left picture shows how new 'penthouse' apartments will be constructed on top of the buildings. Lastly, the bottom right picture shows how balconies will be constructed to one of the sides of the buildings. (The illustrations are made by the architectural company that designed the 'conceptual design' of the renovation project).

A non-profit housing association owns the four multi-family apartment buildings, and the apartments are rented out as social housing. The Danish social housing sector builds on a tradition of tenants' participation and self-governance, so tenants living in the buildings elect a housing estate board responsible for the daily management and financial governance of the estate (Engberg, 2000, p. 12). In the energy renovation project, the estate board consists of seven members, whereas four of them are involved in the design and planning of the project. The role of the four members (referred to as the 'estate board members' through rest of the thesis) is to represent the interests of the tenants in the energy renovation project and make decisions on their behalf unless the decisions affect the rent of the tenants. If a decision affects the rent of the tenants, the tenants have to vote on a motion decide on not in a yearly or extraordinary assembly meeting. In this energy renovation project, the tenants vote in favour of the project in January 2015 to an increase in rent at approximately 900 DKK per square meter.

Since a housing association owns the buildings and the estate board attends to the daily management of the buildings, the role of the 'building client' is shared among a few organisations. That is why, the thesis refers to the 'client organisation' as several people are involved in the management and strategic planning of the buildings, their management and the living conditions in the buildings. A housing association owns the buildings together with other housing estates. A housing estate, also called the housing section, manages the buildings daily. Moreover, then there is a non-profit administration organisation which supports the housing association and their housing estates in strategic management and long-term planning of the maintenance of the buildings. The administration organisation supports multiple housing associations where each association might own several housing sections. The administration organisation helps housing associations with planning and undertaking building projects and renovation projects. In this case, the project manager (referred to as the client's manager) works at the administrator organisation and supports the estate board in the role of the building client. The housing association is represented at most meetings where representatives from the estate board and the administrator organisation meet, but the housing association does not figure in the design meetings observed and is not referred to by the interviewees. As a consequence, the thesis only focuses on the four estate board members and the client's manager who are involved in the energy renovation project.

This thesis aims to get close to the design interaction of building professionals to observe how they interact with each other and with material objects. Drawing on ethnographic research methods, the thesis aims to *"watch what happens, listen to what is said, ask questions, and produce richly written accounts that respect the irreducibility of human experience"* (Pink et al., 2010, p. 648). Ethnographic research methods are demanding, in the sense that observing everyday activities in organisational settings unknown to the observer is difficult. The observer does not know before carrying out the study of how (or if) different observations relate to each other. This thesis studies one particular energy renovation project to ensure that most of the observations relate to activities in the same project. One case study also allows more in-depth observations compared to multiple case studies where the attention of the researcher is shared on activities happening in multiple cases. In the next section, the project organisation is introduced.

The next section describes the project organisation and why the study focuses on one of the consultancy companies.

THE PROJECT ORGANISATION

The energy renovation project began in 2012 with preparations and development of the vision for the project. In a newsletter to the tenants, the administration organisation illustrates the process in three phases as shown in figure 4.3. For each of the three phases, the organisations that are involved in the project change. In the 'vision phase,' the administrator organisation engages with other consultants than in the 'design phase.' Furthermore, in the 'construction phase,' contractors that previously have not been part of the project become part of the project. This thesis focuses on the 'design phase' from 2015 to 2016.

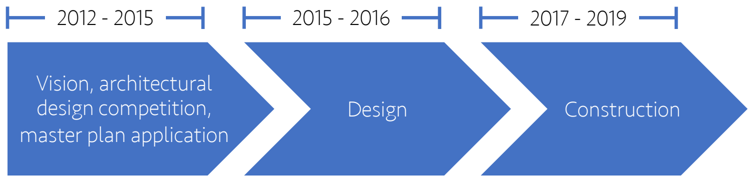

Figure 4.3: The figure shows a timeline divided into three phases that have been presented for the tenants in a newsletter dated April 2016.

During the design phase, the organisations illustrated in figure 4.4 are engaged in the project. The companies are anonymised since their names are not important for the study. Instead, the companies are distinguished based on the type of service they provide.

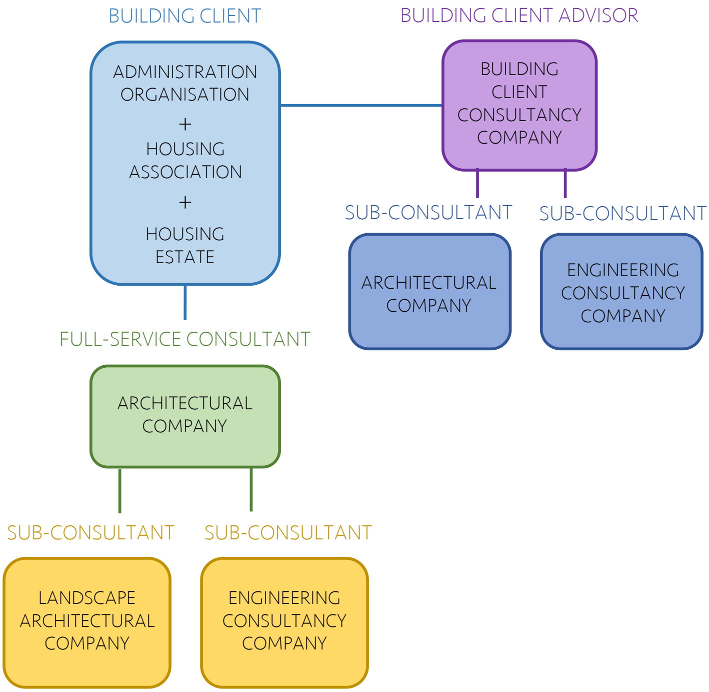

Figure 4.4: The figure shows the project organisation. The building client is illustrated as a joint position including the three non-profit housing organisations. To the right side of the building client, the building client advisor and their sub-consultant are illustrated, because they support the building client. The architectural company is illustrated underneath the building client because they are the full-service consultant to the client. During design, the architectural company has two sub-consultants: The landscape architectural company and the engineering consultancy company.

The architectural company that is the full-service consultant on the project is responsible for delivering the design and construction of the energy renovation project to the building client. The architectural company and the landscape architectural company won the architectural design competition mentioned in figure 4.3 and continued as partners in the project. The building client advisor and their two sub-consultants are hired during the design phase to support the building client in assessing the design of the energy renovation project. Correspondingly, the engineering consultancy company that is sub-consultant to the full-service consultant is also hired in the design phase to assist the delivery of the design of the energy renovation project. The landscape architectural company delivers the design of the green areas around the buildings and is not involved in the design of the buildings. Their work is therefore not part of the thesis. The building client advisor and their sub-consultant did not figure in the observations during the fieldwork, and they are not included either.

The architectural company that is the full-service consultant in the project has designed the conceptual design of the energy renovation project during the architectural competition mentioned in figure 4.3. The design work performed in the 'design phase' is a development of the conceptual design made by the architectural company. However, even if the role of the architectural company is the full-service consultant, the task to develop the conceptual design into detailed design drawings and documents is transferred to the engineering consultancy company during the design phase. The architectural company is a foreign company, while the engineering consultancy company is a Danish company. The building client insists that a Danish company should make the detailed design of the energy renovation project, since a Danish company would better, according to the building client, ensure compliance with Danish building regulations, provide information to the (mostly) Danish speaking tenants and serve with know-how about the Danish construction industry. For these reasons, the engineering consultancy company takes over the design of the energy renovation project during the design phase. However, the architectural company still approves significant design decisions made by the engineering consultancy company to ensure that its architectural vision remains intact.

This thesis focuses on the design work carried out at the engineering consultancy company for three reasons. First, the engineering consultancy company is responsible for the development of the conceptual design from the architectural company which means that most of the design work in the project happens in the engineering consultancy company. Second, the engineering consultancy company does not only provide engineering competences to the project. Besides project management and engineering disciplines, the company also provides the renovation project with architectural design competences. The company has previously acquired architectural companies, and at the time of fieldwork, the company has a division of architects employed. The company provides the energy renovation project with competences within project management, architectural design, and engineering disciplines (e.g. construction, ventilation, electricity, heating, plumbing, and energy performance). In this way, the design work at the company involves interactions between building professionals with different training and backgrounds who might approach the design of energy performance differently. Third, the designers who are mostly involved in the energy renovation projects have their working desks in the same office in the same building, making it easy to follow them and their design interactions.

This thesis focuses on the design interactions happening at design meetings since designers explicitly bring up issues at these meetings. Observations made in between the design meetings show that the designers mostly sit by themselves at each of their working desks and working on design issues individually. Once in a while, the designers discuss issues in between the meetings, but as a researcher, the spontaneity of these discussions is difficult to record and document. Furthermore, issues regarding energy performance are not brought up in between meetings during observations. On the other hand, issues regarding energy performance are brought up several times during the design meetings, as illustrated in the analytical chapters. Therefore, this thesis focuses on these specific discussions about energy performance during design meetings. The next section introduces the designers who participated in these meetings.

The next section introduces the backgrounds and roles of the involved designers and presents an alternative view on the process of energy renovations.

THE PARTICIPATING DESIGNERS & THE 'ENERGY TRAIL'

This thesis focuses on the design interactions happening at the engineering consultancy company with the occasional involvement of people from the building client organisation. The purpose of this section is to introduce the designers that are involved in negotiations concerning energy-saving design features (see table 4.1). The list of designers does not include every person in the energy renovation project, but only those people who are relevant for the subsequent analysis. The people involved in the negotiations are anonymised since their identities are not necessary for the thesis. However, their role in the energy renovation project and their areas of responsibility are important, since this information puts their actions in perspective. In the analytical chapters, the research participants are referred to by abbreviations in the transcripts of video recordings to indicate their role in the project. The abbreviations are also shown in table 4.1.

The design team responsible for designing the energy renovation project at the engineering consultancy company is divided into two groups. One group includes the designers working on the engineering disciplines such as constructions, ventilation and electricity. The other group includes the designers working on the architectural design of the buildings, that is, the details about the appearance of the buildings, including specifications of materials and dimensions of building components. Both groups have construction architects who help either the architects or the engineers with designing the respective areas. Even if all the designers sit in the same office, the designers in each group have physically close to each other to support the coordination of the design tasks.

Role in the project	Responsibilities	Abbr.
Project manager	Managing the project for the engineering consultancy company and coordinating design tasks among the engineering group	PM
Ventilation engineer	Designing the ventilation system	VE
Construction engineer (new buildings)	Designing concrete constructions for the ‘new building’ part of the project	CEN
Construction engineer (existing buildings)	Designing concrete constructions for the ‘existing building’ part of the project	CEE
Heating and plumbing engineer	Designing the heating, domestic water, and drainage systems	HPE
Project architect	Coordinating design tasks among the architectural group	PA
Architect #1	Mostly drawing detail and section drawings	A1
Architect #2	Mostly writing work specifications for the contractors (the so-called ‘prime contracts’)	A2
Architect #3	Mostly writing work specifications for the contractors (the so-called ‘prime contracts’)	A3
Construction architect #1	Mostly drawing detail and section drawings	CA1
Construction architect #2	Mostly managing the BIM models (note)	CA2
Construction architect #3	Mostly drawing constructions for the new building part of the project	CA3
Energy consultant	Guiding the design regarding energy and indoor climate to the other designers	EC
Client’s manager	Project manager for the building client organisation	CM
Estate board members	Taking decisions that affect the tenants or the tenants’ rent	EBM

Table 4.1: The table shows a list of the designers involved in the design interactions described in this thesis. Each designer is described with the role and responsibility in the project as well as abbreviation used in the video transcripts in chapter 6.

In case of designers having the same role in the project (as for the architects and construction architects), their order is based on the number of times they appear in the video transcripts of design interactions presented in chapter 6. In this way, architect #1 appear more times than architect #2.

All of the designers listed in table 4.1 are working on the energy renovation project daily during the fieldwork, except for the energy consultant. The engineering consultancy company distinguish between 'disciplines' and 'specialists' when it comes to the role of the employees. Employees are working within 'disciplines' are using most of their time on one specific project, attending to the project from a particular point of view (such as constructions, architecture, or ventilation), and deliver project material on that particular project (such as drawings and documents). Employees working as 'specialists,' on the other hand, are allocated to several projects at the same time and only provide guidelines to the people delivering the project material. In this way, specialists do not 'draw' or 'write documents' directly, but give other designers input by commenting on design proposals. As examples of 'specialist roles,' the research participants mention the topics of energy and indoor climate, fire safety, and acoustics. The role of the energy consultant is as a 'specialist' ensuring that the project achieves the energy goals set by the building client. However, since the energy consultant is a specialist, he attends several other projects and is absent from many of the design meetings held among the designers. As described in chapter 6, his absence leaves the other designers with questions about how to handle energy performance in the project.

This thesis studies design processes that span across 11 months from August 2015 to June 2016. In August 2015, the design team was hired for the design task of delivering a detailed project design in the summer of 2016. In June 2016, the designers delivered the project design to the building client and the bidding contractors and observations for this thesis ended. In the course of the 11 months, the designers involve themselves in a tremendous number of design problems and proposed solutions. A portion of these problems and suggestions for solutions relates to the future energy performance of the buildings. This thesis terms such design areas for 'energy-saving design features' since the designers work with these design issues and solutions with an aim to reduce the energy consumption in the existing buildings. Simultaneously, the term 'energy-saving design features' does not denote any particular ways to save energy, and therefore, this thesis lets the designers define what it means to 'save energy through design.'

Even if this thesis let the designers define what 'energy-saving design features' are in the specific case, the observations focuses on identifying negotiations around three criteria found in research papers, namely negotiations concerning the thermal envelope, technical installations, and occupant behaviour (see the section Working with the material in chapter 3 for clarification). Based on this identification, the analysis found several design issues and solutions which the designers discussed through the design process. However, the many discussions varied in length and magnitude since some issues were just touched upon for a few minutes and other issues took up the attention of the designers for months.

This thesis focuses on the design issues that took up the attention of the designers for longer periods because these issues were recognised by the designers as 'problematic.' Problematic situations are interesting because they show how the designers make the design problem knowable through different actions and how they make the problem actionable by suggesting solutions to solve it. Further analysis identified prolonged and significant negotiations concerning five issues. The five issues identified concern mechanical ventilation with heat recovery, definition of the energy requirements, thermal bridges in the facades, thermal insulation of the basements, and thermal insulation to prevent floor heating systems in heating downwards. As an alternative way of illustrating the design process opposed to the linear models presented in the existing literature on energy renovations (e.g. Thuvander et al., 2012; Nielsen et al., 2016), this thesis presents the design processes as 'trails in a landscape' (see figure 4.5).

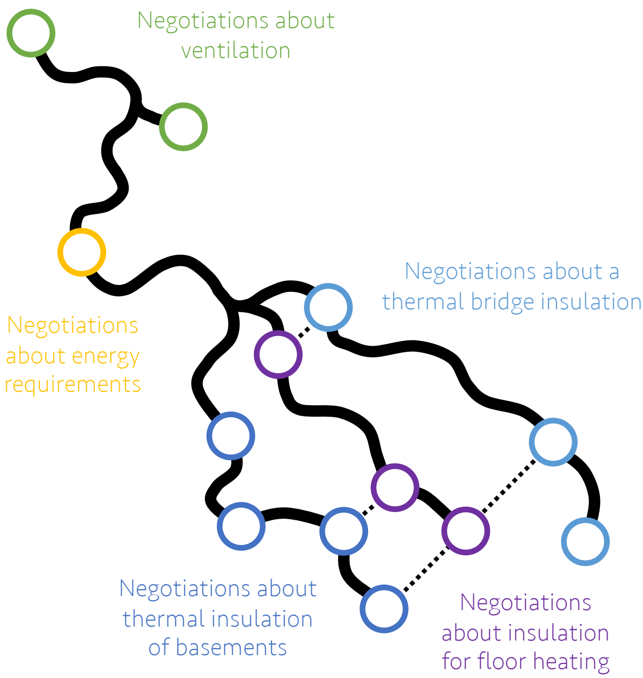

Figure 4.5: The figure illustrates relations between moments of negotiations concerning energy-related issues in the energy renovation project. The relations are illustrated as 'trails' in a map and signify how the designers move from one issue to another in the course of the project. The trail begins in the top left corner and ends in the bottom right corner. The colours represent the issues negotiated among the designers, and the dotted lines indicate when negotiations happen at the same design meetings.

The metaphor of 'trails' illustrates how design processes involved in energy renovation projects are simultaneously predictable and unpredictable, stable and unstable, and include planned and unplanned actions. The purpose of the metaphor is to illustrate the synchronous making of a map and walking of the designers. Each step the designers take into the unknown landscape of the building design, the terrain (the building design) becomes 'more-known' and simultaneously 'less-known' to the designers (Yaneva, 2005). The designers may predict which direction to take, but they cannot foresee which design struggles lay ahead. The trails of the designers are both the actions taken by them, but also the materialisation of what they know at a given time in the project. The designers become aware of design issues in particular situations and tie these issues to situations that happened earlier in the design process. Simultaneously, the designers can make 'realisable courses of action for the future' (Comi & Whyte, 2017) by expecting how they will deal with the issues revealed to them in particular situations. However, the metaphor of the trails highlights how the trails are only made when the designers walk it (design it). That is, the trail illustrated in figure 4.5 is an ex-post description of what the designers have done and not what they are going to do in the future. The illustration of the 'energy trail' for this energy renovation project is an alternative way of illustrating design processes in energy renovation projects to the linear models described in the existing energy renovation literature. The trail metaphor illustrates the design processes as non-linear, similar to the 'energy renovation journey' presented by Mosgaard & Maneschi (2016).

The five design issues related to energy performance illustrated in figure 4.5 involve negotiations among the designers and interactions between the designers and material objects, all of which help the designers make the energy renovation knowable and actionable. Two of the issues highlight negotiations more than the use of material objects, while the remaining three issues highlight the use of material objects more than the negotiations. The two issues concerning the ventilation system and the energy requirements underline the negotiations, translations of interests, and trials of strength that happen during design of energy renovations. The three remaining issues emphasise how the designers' interaction with material objects help them to discover new insights and help them solve the issues they are facing. The analysis is divided into two parts to emphasise the two different foci on negotiations and material objects respectively. However, even if the analysis is divided into two parts, all of the five issues, and perhaps most of the design interaction happening in the project, involves both negotiations and material objects. This thesis simply foregrounds negotiations in one part and the use of material objects in the other part.

The following two chapters present the analysis of this study. Chapter 5 focuses on how the designers make energy-saving design features knowable and actionable through negotiations of interests. Chapter 6 focuses on how the designers engage with material objects to help them make energy-saving design features knowable and actionable.

CHAPTER 5

Knowing & Acting through Negotiations

INTRODUCTION

This chapter illustrates two examples of how the designers attempt to convince others to follow their interests. The two examples highlight how design processes are political, in the sense that designers actively promote specific interests through their actions. The thesis does not suggest that the negotiation of interests only happen in these two examples. If anything, negotiation of interests happens in all of the five examples illustrated in this thesis. The reason why this chapter highlights the negotiation of interests is because the two examples start by involving designers who have a desire to influence the choices of others. In this way, both these examples tell stories about how designers use devices and tricks to further their interests.

This chapter describes two empirical examples. One example is about a discussion revolving around the decision about which kind of ventilation system the buildings should have installed. The other example is about the specification of energy requirements. The two examples are presented in chronological order, meaning that the first discussion about ventilation systems began before the case about energy requirements. The discussion about ventilation systems began in August 2015 and continued into October 2015. The discussion involves an engineering consultant, a representative of the client consultancy, and the estate board, as well as several material objects circulating these actors. The case about energy requirements occurs when the energy consultant from the engineering consultancy company writes a document in November 2015 and shares it with the building client and the local authorities. The document refers back to project documents written in 2012 and 2013 bring statements from this time into the 'present' of 2015.

VENTILATION CONTROVERSY

This section describes negotiations revolving around the design of mechanical ventilation with heat recovery in the project. The discussions start in August 2015 when the designers at the engineering consultancy company are hired to design the energy renovation project. The topic of discussion is the concept of ventilation systems. The disagreement is about what would be the 'best' concept for the housing estate and the empirical example shows how the involved people present each other with arguments in favour and against two different concepts. The two concepts are centralised ventilation versus decentralised ventilation[2]. The discussion last for three months and involve the ventilation engineer from the engineering consultancy company, the client's manager from the client consultancy company, and the housing estate board members. The ventilation engineer has one take on the ventilation debate, and the client's manager has another take. The role of the estate board members is that they are the clients, and in the end, they have to decide which ventilation concept should be installed in the buildings.

DECENTRALISED VERSUS CENTRALISED VENTILATION

In August 2015, the designers at the engineering consultancy company were introduced to the energy renovation project. The first month or two, the designers examine the energy renovation project as it is described in project documents and drawings to figure out the characteristics of the design and which requirements the project should fulfil. At this time, the project has already been designed as what the research participants call 'conceptual design' by previous designers in an architectural company. The assignment of the designers at the engineering consultancy company is to turn the 'conceptual design' into what they call a 'detailed design project.' In this way, the designers receive project material where 'conceptual' decisions for the design have already been made. However,

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[2] Centralised ventilation is, as described by the research participants when one ventilation unit supply air to several apartments. The unit typically stands in either the basement or on the roof from where one gains service access. Decentralised ventilation is when a ventilation unit stands in each apartment and only supply that particular apartment with air. Decentralised ventilation means that each apartment is an independent unit and service must be done in each apartment.

many details and questions about the 'conceptual design' remain, and the designers are hired to explore and describe these details.

This example revolves around the topic of ventilation, and, like his colleagues, the ventilation engineer at the engineering consultancy company begin his work by conferring with the client consultancy company. The client consultancy company assists the client, the housing estate board, in any technical details and descriptions about the renovation project. The estate board consist of laypeople where only one of them has previous experience with the design and planning of construction projects[3]. The estate board members do not regard themselves as being capable of assessing technical engineering or architectural drawings and descriptions by themselves. The estate board members are more interested in the appearances of the buildings, the spaces and their functions, as well as project economy. All technical detail, which the client consultants deem not relevant for the estate board members, the client consultancy company does not burden the estate board members with such details. The ventilation engineer, therefore, turns to the client consultants to hear about how they imagine the ventilation system and which requirements the ventilation system should comply.

The ventilation engineer meets with client consultants during the first month. At the meetings, the engineer learns that the client consultants want to install decentralised ventilation in the buildings.

> *"We had some preliminary meetings with (the client consultancy company) about centralised and decentralised ventilation where we discussed various things. And they made it clear that they were very keen on getting decentralised units in (the housing estate) (…) The building client expressed a request for decentralised units because they stated that they had had unfortunate experiences with centralised units." (ventilation engineer)*

The client consultancy company manage numerous housing estates, and several of these estates have been renovated recently. Together with the respective housing estate owners, the client consultancy company decided to install centralised ventilation in similar multi-family apartment buildings like the one in question here. It is based on these renovation projects that the client consultants have experienced some 'unfortunate situations.' The client's manager from the client consultancy company explains the situations in the following way:

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[3] The person was hired in a municipality and handled building permit applications for more than ten years.

> *"It is typically problems with adjustment because our residents very often block the supply air valves. You can have a ventilation unit which supplies ten dwellings or twelve dwellings in which just three or four of the residents put plastic bags and duct tape over their supply air. Then the whole system is going out of balance. It is almost impossible to avoid. We must notify and gain access to all ten dwellings, go around and look, and inspect, and readjust. It is very, very difficult to deal with." (client's manager)*

The 'misbehaving actions' of the residents by blocking supply air valves create problems for the client consultancy company. They manage the buildings and make sure that technical installations, such as ventilation systems, run as they should. The mentioned buildings are installed with centralised ventilation which means that the same unit supplies and extracts air from ten or twelve apartments at the same time. When residents block the valves, the pressure in the next-door apartments becomes higher and makes the neighbours feel more draught from their ventilation valves. As the client's manager describes, the system is going 'out of balance' and needs to be adjusted to 'normal' operation by their caretakers. The client's manager and her colleagues deem centralised ventilation problematic based on their previous experiences.

The ventilation engineer finds the proposition of installing decentralised ventilation in the housing estate to be odd. According to him, multi-family apartment buildings, such as these buildings, typically get centralised ventilation. He decides to seek the advice of ventilation manufacturers.

> *"I called some of the ventilation manufacturers, and they say that decentralised units are good for single-family houses - and not for other types of buildings. Simultaneously, the majority of the units which are installed is centralised units. There are not particularly many decentralised units that are being installed." (ventilation engineer)*

The ventilation engineer wants to illustrate his take on the advantages and disadvantages of centralised and decentralised ventilation to the client consultants and the estate board members. He writes a document stating his point of view. The document is written to the client's manager and the purpose of it, as stated in the introduction, is to 'illustrate the technical, energy- and service-economic advantages and disadvantages' by the two concepts of ventilation. The document focuses on the service life of units, costs related to installation, service, replacement and electricity usage, the location of ventilation ducts and units, as well as a technical report of the two systems. The technical report is listed in bullet points with several abbreviations. In the very beginning of the document, the ventilation engineer's point of view becomes visible:

> *"Given that a decentralised solution is an alternative to a centralised ventilation solution – which not until recent years has become popular in the Danish housing stock – is the document structured around the variations from the decentralised solution compared to the conventional centralised unit composition" (Except from the ventilation document dated 14-10-2015).*

The ventilation engineer compares the two systems by calling the decentralised system 'an alternative' to the 'conventional' centralised system. In this way, the document, and thereby the ventilation engineer, seems to favour centralised ventilation. The document also states something about service and repair of decentralised ventilation units:

> *"If deciding on a decentralised solution, it requires access to the apartments during servicing and repair – which will be an inconvenience for occupants, caretakers, as well as service technicians (…) Concerning repairs, are the costs expected to be somewhat higher for a decentralised versus a centralised solution. The risk of components on 270 units break is larger than with 15 units." (excerpts from the ventilation document)*

The document calls the decentralised system for 'an inconvenience' during service and estimates the risk of units failing to be higher than with a centralised system. The document ends by recommending centralised ventilation based on statements about service of decentralised units is a challenge, their expected service life is shorter, and their service expenses deemed to be higher than centralised units. The ventilation engineer himself describes it in the following way:

> *"We draw up a note which tried to be rather objective regarding decentralised and centralised units with a final recommendation to go with centralised units. I cannot remember it in details, but I made like a section which was generally understandable, then I made a technical section, and then I made a recommendation in the end. We looked at how it worked, what the expected installation expenses would be, and also trying to put some numbers on some life cycle costing in correlation with these units."*

The ventilation engineer sends the document to the client consultants and the estate board members and presents his point of view at a meeting where they are all present. After the meeting, the estate board members do not know what they should decide concerning ventilation. According to them, the ventilation engineer did not recommend one system over the other. As one board member states:

> *"I remember the presentation, but he did not recommend any of them. He said that it was indifferent what one chose. There would be practical and impractical things by both systems." (estate board member)*

The empirical example shows how the interests of the client's manager and the ventilation engineer differ. The client's manager is interested in installing decentralised ventilation based on 'unfortunate' experiences with previous renovation projects. The ventilation engineer suggests the client and the client's manager install centralised ventilation based on statements about service and replacement costs and service life of the units. At the meetings between the two designers, the client's manager presents the ventilation engineer with their 'program of action' (Latour, 1991). That is, they intend to install decentralised ventilation. The ventilation engineer might have 'subscribed' (Akrich & Latour, 1992) to this idea and could have started to design the ventilation system. However, based on his experience with designing similar buildings and interaction with ventilation manufacturers, the engineer makes an 'anti-program' to the interest of the client's manager. The ventilation engineer draws up a document in which he recommends a centralised system. He sends it by email to the estate board members and the client's manager. In this way, he lets the document be circulated among the involved project participants before he presents it at another meeting. His attempt to convince both the client's manager and the estate board members to follow his suggestion fails. The estate board members leave the meeting and do not feel that he has recommended any of the two ventilation concepts. They are not convinced about any of the systems at this point, and the decision remains open.

ENROLMENT OF ALLIES

The estate board members learn from the client's manager that it is possible for them to visit another engineering consultancy company to get their opinion on the choice of the ventilation system. The estate board members are interested in decentralised ventilation, but they do not know for sure if their money is well spent if they decide on decentralised ventilation. The estate board members decide to take the client's manager upon offer and visit the other engineering consultancy company. Because the interest of the client's manager and the proposition to hear more about decentralised ventilation are consistent, the decision to visit the other engineering consultancy company can be regarded as an 'anti-program' (Latour, 1991) to the ventilation engineer's presentation. The client's manager invites the estate board members and the designers from the engineering consultancy company, including the ventilation engineer, to the other engineering consultancy company.

The project participants get a presentation by two engineering consultants from the company's department of energy consumption, indoor environment and ventilation. The two engineering consultants present information about ventilation systems, why it is relevant to ventilate, which technical concepts there exist, and how the building regulation becomes stricter each year concerning airtightness. The information that is presented to the project participants resembles the information given by the ventilation engineer in his document. The information consists of technical values, such as the number of litres of air required by ventilation, and abbreviations such as VAV for variable air volume. The client's manager describes some of the information in this way:

> *"We made a trip out there (to an engineering consultancy company) where two engineers told us about ventilation in general, and in particular, about decentralised versus centralised ventilation, advantages and disadvantages, experiences, what you do at the moment, and so on." (client's manager)*

Even though the presentation by the two engineering consultants does not seem to favour either of the ventilation concepts, they present a calculation of possible savings by different systems. In the calculation, the engineering consultants compare different options. Among the options, the estate board members can compare a decentralised system with a centralised system. Moreover, based on these calculations, decentralised ventilation gives the client up to 46 per cent greater savings compared to centralised ventilation, and the payback period of decentralised ventilation is seven years shorter than the centralised ventilation (from 18 to 11 years). From their calculation, decentralised ventilation seems more beneficial than centralised ventilation. The engineering consultants are not able to give project participants any financial calculations based on the energy renovation project since the engineering consultants do not know details about the project design. An estate board member recalls the situation in the following way:

> *"We wanted to hear about how great the expenses actually would be with them. I do not think that we got that part of the matter a hundred per cent covered. The operation expenses, you might say. Because, (the engineering consultants) could not spit some numbers out, because they did not know how large units we were talking about. So, it was a little limited, but it was because we were a bit too hasty." (estate board member)*

The presentation from the engineering consultants is therefore mainly based on general information about ventilation systems and concepts. After the presentation, the two engineering consultants invite the project participants into their laboratory to see decentralised ventilation units. According to the estate board members, they are not interested in seeing centralised ventilation units, because they already know these units from their neighbouring buildings which have such units standing on the roofs. As an estate board member says:

"We did not need to see centralised units. We did not feel that we needed to see them, because we could see them on the other side over there [on a neighbouring building]. And we have already heard those units. When they built those yellow buildings over there which have those centralised ventilation units. We could hear them over there on the roofs. We can still hear them from time to time when they forget to change filters. Then they stand and shriek over there." (estate board member)

According to the estate board member, they did not need to see centralised ventilation units. In agreement with the client's manager, the engineering consultants had prepared to show the estate board members decentralised ventilation units. In the laboratory, the project participants see three different versions of decentralised ventilation units from the same manufacturer. The physical units allow the estate board members to hear them as they run and see how they look like on the outside as well as on the inside (see figure 5.1).

Figure 5.1: The estate board members look at decentralised ventilation units in the laboratory of an engineering consultancy company. The left picture shows how a board member points at the white filter in a unit. The right picture shows another type of unit.

According to the estate board members, the decentralised ventilation units do not make much noise. One of the board members compares the units with a fridge:

"We found out that the units make noise at 38 dB. In other words, it is under the level of whisper [he whispers to indicate the level of sound]. (…) It makes noise on par with how a fridge which runs." (estate board member)

Shortly after the visit to the engineering consultancy company, the estate board members decide about which ventilation to install in the housing estate based on what they have seen. They have received a document by the ventilation engineer who states the advantages and disadvantages of the two types of ventilation concepts. They have heard about the experiences with centralised ventilation units from the client's manager as well as seen and heard centralised units on their neighbouring buildings. They have seen, heard and examined physical decentralised units in a laboratory. With these experiences, they have also received much technical and economic information about ventilation concepts. In the end, the estate board members decide to get decentralised ventilation in the buildings.

The experience of seeing physical ventilation units has a significant impact on the estate board members. One of the board members describe the experience in the following way:

> *"For my part, it was the thing about that it was more tangible. That you could see the units. Find out how they worked and the more practical about it. If I have to be honest. That is how I am. A geek [laughs]. I like to have the thing in my hands. That you can see how large the unit is. How much space it takes up. How much noise it makes. More practical stuff than something else." (estate board member)*

The tactile sense and the audio-visual sense of the ventilation units made the estate board members decide on decentralised ventilation, while they remain sceptical towards centralised ventilation.

DIFFERENT KINDS OF KNOWING VENTILATION

The empirical example shows that a choice of technology is not only a matter of technical, economic considerations followed by implementation and use, but the choice of technology may involve different viewpoints, disagreements and attempts of persuasion.

Concerning laypeople taking decisions regarding technologies, they may have little awareness of before involvement in construction projects, the sensorial experience of technologies is vital for their assessment of the technology. The technical and economic language of the engineering consultants and the ventilation engineer may be advantageous when professionals discuss such matters, but when it comes to laypeople, the tangible dimension of the material objects are crucial.

The empirical example also shows how designers can take greater and greater artillery to design discussions. The presentation of technical and economic arguments in documents may be one way of presenting advantages and disadvantages. Bringing in more consultants and experts into the discussion may also be a trick. Moreover, not least, mobilising nonhuman agents such as the physical ventilation units may be a third strategy. Whether the first, the second or the third strategy will be best in specific situations depends on the situation; however, it might be interesting to see how practitioners mobilise different strategies in attempts to achieve their desires. In this case, the physical ventilation units did the trick. However, in other cases, it might be other strategies that are necessary.

The clients do not know much about ventilation before the negotiations, but they are made aware of aspects through engagements with documents, presentations, consultants, and physical units. Based on their knowledge, they can act and decide which system they prefer. It is through the practical accomplishments involving professional know-how, technical descriptions, and economic estimations that the decision is made after having been subject to 'trails of strength'. The decentralised ventilation concept wins the trail, while the centralised ventilation concept is defeated.

The next section presents the negotiation around the re-specification of the energy requirements in the project.

RE-ASSEMBLING ENERGY REQUIREMENTS

This example shows how the energy requirements in an energy renovation project can change in the course of the design process and accommodate to the situation of the designers. The example takes its starting point in a moment in November 2015 where the energy consultant devises a document which is referred to as 'the energy document' in the rest of the text. At this time, the designers are preparing project material to apply for a building permit. The aim of their work at this time is, therefore, to collect and devise project documents and drawings which state how the renovation project comply with the building code. Afterwards, the local authorities process the project documents and drawings, and they assess if the project can gain a building permit or not. The purpose of the energy document is, therefore, to describe how the project participants expect to comply with the energy requirements in the building code. The section first describes how the energy consultant devises the energy document and then it shows how he uses the document to further his interests.

DOCUMENTS AS SPOKESPERSONS

Documents, in ANT terms, 'speak on behalf' of others or other things. Statements in documents refer to the work of others or developments far away from the document but 're-presented' by the document (Latour, 1986). In this way, the documents may act as 'spokespersons' (Callon, 1986a). This section illustrates how a document about energy requirements refers to statements made in other project documents and in this way 'speaks' on behalf of others, such as the client. The energy consultant writes the document with the purpose of finding out which energy requirements the designers should comply in the project. With this aim, he gathers previous project documents and summarises their statements about energy requirements. The energy consultant, as a 'specialist' in the engineering consultancy company, has limited time to spend in the project, because he also has to attend other projects. Looking through previous project documents is a relatively quick and easy way for him to get an understanding of the client's wishes in regards to energy performance. The energy consultant and the rest of the designers at the engineering consultancy company have not been part of the project before August 2015. The previous documents illustrate the interests of stakeholders from project initiation and until the energy consultant becomes part of the project. The four documents he finds are the following:

1. An application for funding from the Danish National Building Fund from 2011
2. A briefing about the international architectural competition from 2012
3. A competition entry made by the winning design team from 2013
4. A jury statement about the winning project also made in 2013

All of the four documents are crucial documents in the sense that they represent vital moments for how the project became in 2015. Without funding from the National Building Fund (NBF), then the project might have ended in 2011-2012, or some aspects of the project might have been dismissed. The architectural competition of 2012-2013 has changed the project to the conceptual design made by the winning design team. If another design team had won, the project might have looked differently. In each of their way, the documents paint a picture of the energy renovation project. The energy consultant goes into the documents and finds statements about energy requirements. The first statement he finds is from the application.

> *"The ambition with [the renovation project] has been from the beginning to reduce the buildings' energy consumption to passive house level to the extent it would be technically and financially possible. It turns out that it is not financially profitable to go down to 15 kWh/m2/year to meet the requirements for Passive House for which reason it is decided as a minimum to comply with BR2015 (30 kWh/m2/year). [The renovation project] will however still incorporate passive house in the renovation, i.e. requirements for airtightness, insulation and ventilation with heat recovery will still be a part of the energy concept." (excerpt from the application for funding at the National Building Fond in 2011).*

The statement mentions the ambition of reducing the energy consumption of the buildings to 'passive house level.' Based on estimations made by the client or their consultants, the authors of the document have deemed the goal of the passive house for 'not financially profitable' even though the statement does not explain on which grounds this estimation is made. According to the energy consultant, the written statement makes the client 'ambitious.'

> *"I would say that they have been rather ambitious about energy consumption. That is what you express if you say, "we want to live up to the building code's requirements in 2015." And it was at a time around 2010. Application for the National Building Fond was in 2011. Well, if you at that time say that you want to comply with requirements for passive houses, then it means that you are very ambitious. But it is not more precise than that." (energy specialist)*

The next document which the energy specialist chooses is the competition briefing from 2012. The purpose of the document is to introduce possible entrants to the characteristics of the competition and the renovation project. The document contains information about the jury, competition schedule, prizes, competition rules, required competition documents, description of the housing estate, and description of the objectives of the renovation project. The energy specialist selects the statement from a section with the headline "Environmental improvement and energy efficiency".

> *"As a minimum, the renovation of the buildings must comply with all requirements set out in the 2010 Building Regulations (BR10). NBF only supports Energy Class 2010 buildings, but the intention is to seek funding for all other interesting energy-reducing initiatives taken in connection with this competition from various funds and subsidy schemes. As a minimum, the new building facilities must comply with Energy Class 2015 requirements and insofar as possible also with Energy Class 2020 requirements or even stricter requirements, always provided that such requirements can be met within the budget approved by the client." (excerpt from the competition briefing documents)*

From the previous statement made in the application to the statement above, the energy requirements have changed. The application states that the project should comply with the energy class 2015 from the building code. The briefing document states that the renovation should comply with building code 2010, while the new building parts of the project (extension and penthouses) should comply with energy class 2015 or 2020 if possible within the budget. The change in statements makes the energy requirements split in two: One set of requirements for the renovation of the existing buildings and one set of requirements of the new buildings.

The argument of the statement in the third document suggests gathering the requirements in one set instead of having two. A design team suggests the statement in the architectural competition which later wins the competition. The design team proposes the following:

> *"The ambition of this proposal is to fulfil the energy class 2015 from the Danish Building Code for the existing buildings as well as for the new buildings. This will result in total energy demand for the whole building complex which is considerably lower than if the renovation of the buildings complies with the requirements set out in the 2010 building regulations (BR10), or a little better, and the new apartments fulfil energy class 2020. Fulfilling energy class 2020 would require the use of solar cells for which the situation at present is very unclear in Denmark – especially regarding profitability and rules for payment of surplus electricity from the PV-system. Therefore, we do not recommend to go for energy class 2020 for the new build, but instead, use the available budget for*

> *achieving large energy savings in the existing buildings." (excerpt from the competition entry)*

The last document which the energy consultant refers to is the jury statement where the jury has appointed the winning design team and described their assessment of the project. The document has the following short statement concerning how the winning design will comply with the energy requirements:

> *"Energy calculations are provided for all alternative solutions. The calculations show that the proposed scheme meets the 2015 requirements and also indicates how the 2020 targets can be reached" (excerpt from the competition entry)*

The last statement follows the suggestion made by the design team and presents the energy requirements as being '2015 requirements' and possibly the requirements for energy class 2020.

The energy consultant takes the statements in previous documents presented above as an indication of the client's interests. According to him, the requirements have changed slightly from project initiation and until 2013, but the requirements remain vague. In an interview, the energy consultant states:

> *"The document has been made because there have not been, strictly speaking, any clear indication of what the energy demands have been. They have referred to building code 2015, for example. And as you can see, I have quoted them writing 'approximately' or 'being on par with' 2015 without definitely stating what it is about." (energy specialist)*

This example shows how four documents act as 'spokespersons' (Callon, 1986) for the client and their interest in the energy performance of the buildings. The energy consultant brings the statements forth as 'the interest of the client.' By composing a document with the statements, the energy consultant establishes relations between many 'punctuated actants' (Law, 1992) by referring to the Danish building code, passive house requirements, energy classes, and budgets. In the way these actants are described, they remain 'black boxed' (Latour, 1987) and unquestioned. However, each of them consists of a network of complex relations which is omitted from the energy consultant's engagement with the documents.

The energy consultant knows about the energy requirements in the project from the written statements. Because of his lack of time on the project, the documents provide quick access to descriptions of energy requirements made further back in time. In this way, the four documents make the energy requirements 'durable' (Latour, 1991) by keeping certain statements in the project, while other, perhaps conflicting, statements made around the time when the documents are written omitted from the documents. All the discussions and efforts made to arrive at the statements remain unknown to the energy consultant. All he can know about the energy requirements in the project is what is written down in the project documents.

CREATING AN OBLIGATORY PASSAGE POINT

Once confronted with the statements made in previous documents, the energy consultant decides to suggest an alternative way of describing the energy requirements to the client. According to the energy consultant, the energy requirements are described in an 'imprecise' manner. The documents define the requirements as being 'on par with' or 'approximately' building code 2015, however, the energy consultant argues, the building code 2015 has both requirements for new buildings and renovations, so which requirements does the client refer? The energy consultant does not regard the building code as a 'black box,' and he cannot read from the written statements what the client exactly wants. According to him, the client refers to requirements for passive houses as well as the 2015 and 2020 requirements from the building code. The intention of the energy consultant in writing his document is to 'fix' the energy requirements so he and his colleagues at the engineering consultancy company can continue to specify the building design according to 'more precise' requirements.

In his document, the energy consultant rephrases the requirements to concern U-values and values for ventilation, heat recovery and airtightness of the building envelope. He presents his suggestion for requirements in a table in the document (see table 5.1). The table describes specifications as well as how each specification refers to requirements in the building code and in the Passive House Institute's requirements for renovations (called 'EnerPHit'). In this way, the table links the energy consultant's suggestion to the previous written statements and their references to the building code and passive house requirements. The links associate the energy consultant's suggestion with the past interests in the project and support his proposal for a new set of requirements.

Topic	**Requirement**	**Notes**
Outer walls	U-value ≤ 0.15	Demand in EnerPHit and BR2015 (extensions) Goes beyond BR2015 (renovations) and EC2020
Roofs	U-value ≤ 0.12	Demand in BR2015 (extensions and renovations) Goes beyond EnerPHit and EC2020
Windows	U-value ≤ 0.85 incl. warm edges U-value ≤ 0.80 excl. warm edges Energy contribution of at least 0 kWh/m2 per heated floor area	Demand in EnerPHit and EC2020 Goes beyond all other requirements for thermal transmittance and energy contribution.
Heat recovery	75 %	EnerPhit (conservative calculation)
	85 %	EC2020 demand for ventilation systems that supply one apartment
	1.000 J/m3	Demand in BR2015 for ventilation systems that supply one apartment
Overheating	Max. 10 % above 25°C	Demand in EnerPhit. 10 % of occupancy time is 876 hours
	Max. 100 hours above 27°C Max. 25 hours above 28°C	BR2015 demand. Demonstrated for selected, critical rooms
Airtightness	Infiltration max. 1.0/l by 50 Pa, but 0.6/l as objective	Demand in EnerPHit. Goes beyond BR2015 demands for new buildings

Table 5.1: The table shows how the energy consultant presents his suggestion for requirements in his document. In the 'notes' column, the energy specialist writes how the specifications comply with different requirements. EnerPHit is the passive house requirements for renovations. BR2015 is the Danish building code from 2015. The parentheses refer to specific demands in the building code. EC2020 is energy class 2020 as described in BR2015.

One of the previous documents, the briefing document, states that the requirements should be split in two: One set of requirements for the new building components and another set for the existing building components. In the table, the energy consultant presents the requirements as the same for both new and existing building components. The energy consultant writes the following argument in the document:

> *"To ensure consistent solutions and with it minimize the risk of mistakes at the building site, we work with the same conditions for the whole construction project, so there as far as possible is the same insulation thicknesses in all facades, respectively in all roofs, same windows, same ventilation, and so on." (excerpt from the document)*

The suggestion made by the energy consultant gathers interests shown in the previous documents into 'one set of requirements for the whole construction project.' In this way, the energy consultant attempts to make his suggestion an 'obligatory passage point' (Callon, 1986) to which other stakeholders can 'subscribe' (Akrich & Latour, 1992). The energy consultant describes his efforts in making 'the requirements come together' in the following way:

> *"I feel that we with this note have made the things come together. We both meet the passive house requirements for renovation and the building code 2015 requirements. And then we meet a bit more than just the building code 2015 requirements for renovation because we take the 2015 requirements for extensions. They are a bit stricter. And in some respect, because we comply with the passive house requirements for renovation, that is EnerPHit, then we also comply with the building code 2020 requirements at least in regards to windows as I remember it now. And there are possibly other things as well." (energy consultant)*

If the client decides to follow his suggestion, then they remain ambitious, according to the energy consultant, as illustrated in their past written statements, and the designers at the engineering consultancy company can specify building components according to the values.

The energy consultant wrote the document in November 2015. At this time, the project participants are about to apply for a building permit at the local authorities. The energy consultant decides to send his document to both the client and the local authorities to get their view on it, and, he hopes, get them to accept his proposal. At this moment, the document turns from being a device he uses to know what the energy requirements are in the project to a 'political device' (Schmidt et al., 2012) with which he attempts to convince others about a statement. He sends the document by email to the client and local authorities, and then he meets them to discuss the suggestion. The client's manager describes the document in the following way:

> *"(The engineering consultancy company) has made a proposal in which they state that we do more than 2015 on the whole renovation, which is eighty per cent of the final building, and then we do a little less than 2020 in the new building to reach the same in the whole construction project. They have analysed all the items in which there are circumstances of insulation, such as ventilation, windows, facade, and roofs. So, the whole thermal envelope, actually, how you do that." (client's manager)*

The client, represented here by the client's manager, agree with the energy consultant to follow his suggestion. According to the energy consultant, the local authorities also accept the suggestion:

> *"In (the note), there have been lots of different wordings which you had to convene. And at that moment, I also have looked into the local authority and whether we comply with their demands. They would like to reach 2020 for the staircase which will be built as new – or build as an extension. That is met by having a bit better than in 2015. That is, this part should comply with 2020, but the remaining sixteen staircases, or something like that, should just comply with 'almost' 2015. So, the fact that we are a bit over 2015 as a total weighting, then it comes together. (The local authority) has been fully understanding and accepted it. We have presented it to them, and they have been satisfied. Their ambition is on par with the housing association, I think." (energy consultant)*

The client and the local authorities accept the suggestion from the energy consultant and the designers at the engineering consultancy company can continue designing the energy renovation project according to his specifications.

The way the energy consultant presents his suggestion for a new set of energy requirements resembles an attempt to make an 'obligatory passage point' (Callon, 1986). If the client and the local authorities wish to achieve their interests of an 'ambitious' energy renovation project, they should follow the guidance of the energy consultant and his interest in making the requirements 'more precise.' The energy consultant's table with requirements gathers allies from building codes to passive house requirements. In this way, the energy consultant shows that if the client supports the U-values, the client also gets compliance with the building regulation and passive house requirements. The energy consultant achieves the acceptance of both the client and the local authorities based on the circulation of the document and discussing the suggestion at a meeting. He gains acceptance without any objections, without any significant discussions or negotiations.

IN THE HANDS OF OTHERS

As Latour (1987) notes, scientific statements may become 'facts,' but their faith is the 'hands of other users' (p. 257). In this case, the energy consultant wants to make his 'statement' about a set of energy requirements a 'fact' in the project.

The energy consultant became part of the energy renovation project at the same time as his colleagues in the engineering consultancy company in August 2015. The energy consultant has not been involved in the discussion about energy requirements in the project from project initiation and until August 2015. In November 2015, the designers at the engineering consultancy company prepared the project to apply for a building permit at the local authorities. At this time, the energy consultant revisits the energy requirements to figure out how they can comply with them. The way that the energy consultant knows about the energy requirements is by reading previous project documents. He gathers statements made in different document throughout the project and presents them in his document. The statements represent 'absent things' (Latour, 1986) by referring to discussions and statements made by people previous in the project. The statements are extracted from specific design situations and cleaned up by only presenting some of the statements made.

The energy consultant then uses these previous statements about energy requirements to support his statement about how the energy requirements should be described. He identifies some 'black-boxed' actants which the statements refer to, such as the building code and requirements for passive houses. He then links his suggestion to these actants to show how his suggestion also complies with the requirements stated in the previous documents. In this way, the energy consultant attempts to make an 'obligatory passage point' (Callon, 1986) in which the client and the local authorities can join his interest in how the energy requirements should be described.

The action of the energy consultant when he devises a document and meets with the client and local authorities is based on the previous documents. The energy consultant reacts to the statements in the documents and decides to make a new suggestion. The documents support his actions. Previous documents allow him to gain insights into statements made previously in the project, and his document allows him to explain and enrol the client and the local authorities into his suggestion. The material objects can hold statements stable over time and across places making statements accessible to the energy consultant. The materiality of his document allows statements to be placed next to each other and enable his suggestion to become an 'obligatory passage point.'

The next section summaries the analytical points from Chapter 5.

KNOWING & ACTING THROUGH NEGOTIATIONS

This chapter focuses on how the designers come to know and act on two design aspects, namely mechanical ventilation with heat recovery and the energy requirements, and how these two design aspects get settled through negotiations among the designers. The negotiations begin with disagreements over the definition of the two design aspects and evolve into two processes of negotiation. Both processes include attempts from the designers to convince each other about the 'truth' or 'accuracy' of their statements, and in this way, they strive to define the design features. In their pursuit of convincing each other, the designers mobilise a range of different allies to support their claims. The chapter shows that realising the design ambition of reducing energy consumption in the buildings involves addressing competing concerns and the enrolment of allies. The choice of design solutions hinges on trials of strength where different interests compete to define the design features. It is through these interactions, these negotiations, that the two parts of the renovation become knowable and actionable to the designers.

In the ventilation example, the designers make specifications concerning ventilation knowable through technical descriptions, calculations of cost, visualisations of ventilation principles, plan drawings with illustrations of ventilation ducts, physical ventilation units, and stories about previous experiences. Simultaneously, all these ways of knowing, or presenting, the ventilation systems also create actions, or 'reactions,' from the designers and estate board members. The process of making ventilation knowable and actionable involves translations of interest and trials of strength in how the designers and the board members come to know and can respond to the design problem.

The example concerning energy requirements shows how the energy consultant mediate and translate statements made by the building client organisation into the design process. Representatives from the building client organisation are not present when the energy consultant devises his document; consequently, the written text represents statements made by the building client organisation. However, the mediation is also a translation since the written statements in the energy consultant's document do not shed light on the possible discussions, negotiations and agreements that the building client actors have had before writing their statements. The written statements leave out such negotiations and struggles. The example shows how documents act as spokespersons and create obligatory passage points when the energy consultant attempts to make energy performance actionable in the subsequent design processes.

This chapter highlights how the making of energy renovations involve translations of interest, competing concerns and trials of strength. Realising the ambitious energy requirements in the project concerns the materialisation and verbalisation of interests and the likely conflicts arising from different interests and aspirations in energy-saving design features. The design of energy renovations involves negotiations between different interest in order to make energy-saving design features knowable and actionable.

The next chapter focuses on how the designers engage with objects to make energy-saving design features knowable and actionable.

CHAPTER 6

Knowing & Acting with Objects

INTRODUCTION

This chapter focuses on how designers use material objects during their discussions on three topics. The thesis does not suggest that only the three examples in this chapter show how the designers use material objects. The previous two empirical examples do also illustrate how material objects are used in attempts to persuade others to follow one's statements. The difference between these two chapters is that the present chapter zooms in on design interactions by illustrating how design discussions are supported by and revolve around material objects. Transcripts of interaction sequences accompanied by pictures of the situations bring out the practical achievements of relations between designers and material objects. This chapter emphasises on these practical achievements.

The chapter presents three empirical examples which span five design meetings held across six weeks from April to May 2016. The three examples run in parallel in the course of the period, and sequences of interaction are therefore taken from the same meetings and shown in the three examples. The time of the design meetings is at the end of the fieldwork, and the designers are about to hand over the design to the contractors for the tender procedure. The tender procedure is scheduled for June 2016, but gets postponed a few weeks and ends up in July. Time is of the essence for the designers, and they work hard to reach a final set of drawings and documents before the handover.

The three examples illustrated in this chapter involves the following three topics. The first concerns the design of a joint between constructions where insulation is placed to prevent a possible thermal bridge. The second revolves around the design of insulation of existing basements as well as the new basement. Furthermore, the third involves the design of floor constructions with floor heating and the location of insulation to prevent the heating system in heating downwards.

THERMAL BRIDGES & TREACHERY

This section shows how the energy consultant needs to enforce his interests in the project because the other designers go against his will in regards to the design of a joint between constructions. The energy consultant specifies requirements for insulation in the particular joint and the designers decide to circumvent the requirement. The designers draw something else than specified by the energy consultant. When the energy consultant learns about the 'wrong' design of the joint, he has to get the other designers to correct the drawing and adjust it to his interests. The empirical example shows how design processes are political and sometimes conflicting interests create situations like this one, where designers are forced to change design features back to an original starting point.

This example revolves around an issue regarding thermal bridges. Thermal bridges are, according to the energy consultant, the 'most difficult part' of the energy renovation project. Thermal bridges turn up when heat from inside the apartments get out, or the cold from outside gets in, through less-insulated areas. Thermal bridges are in this way 'weak spots' in the well-insulated thermal envelope. In regards to the energy renovation project, the thermal envelope is 'pierced' by mountings that hold a system of balconies. The fixtures for the balconies go through the insulation in the outer walls and create numerous places where heat can escape or cold enter. The energy consultant aims to reduce these places, if possible, or else reduce the heat losses from them. One way to reduce the heat losses is to insulate places where thermal bridges are expected. Such places are for example in joints between constructions where it is difficult to insulate. This example revolves around the design of such a joint between constructions.

The section describes first a situation where the energy consultant tells an architect and a construction architect about the importance of insulating to prevent thermal bridges. Afterwards, the section illustrates how the designers discuss the same insulation and how they take the liberty to reduce insulation thickness.

INSCRIBING INSULATION

This section illustrates how the energy consultant explains to an architect and a construction architect the importance of insulating to prevent thermal bridges. The situation takes place at a meeting on 19 April 2016, where the three designers go through details of constructions. The architect begins the conversation by asking the energy consultant about insulation. The detail drawing which the designers have in focus is a detail illustrating a balcony floor construction.

A1: You say, fill up with insulation down here *((points, see figure 6.1))*

EC: Yeah but () it if as said if () if matters, that is, if there is something which ()

Figure 6.1: The designers draw their attention towards a detail drawing. The designers are (from the top left corner): The architect, the energy consultant, and the construction architect.

EC: If there is a thermal bridge, so we need to insulate on both sides *((shows hands, see figure 6.2))* () winter garden () how is it? () is it the new ((building))?

A1: Yeah () it is the new building

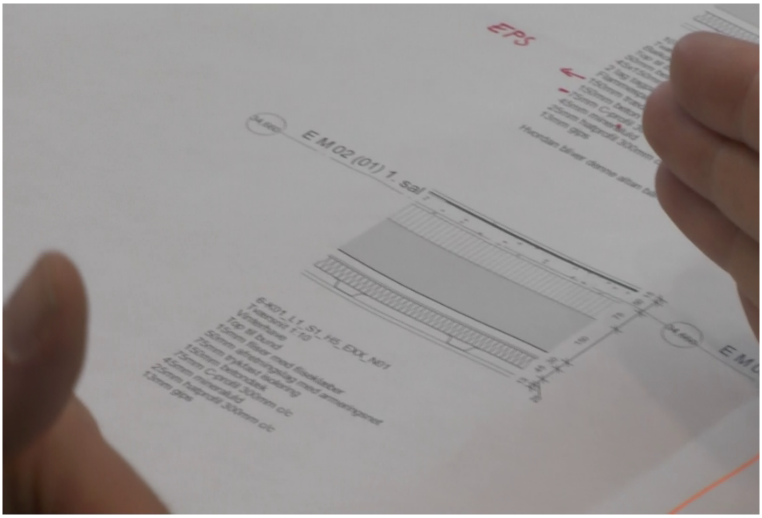

Figure 6.2: The energy specialist shows his hands above and underneath the detail drawing to indicate the location above and underneath the floor construction.

EC: Yeah () then it should be possible () that we *((takes pen from the architect))* () when we are approaching *((begins to sketch, see figure 6.3))* () the floor construction inside, then it is laying here somewhere () inside the apartment () the winter garden () and then () there is some floor build-up here and () what do I know, some mountings and stuff like that () and then the window stands here () isn't it something like this we talk about? () that is, there is a () good gap here *((points, see figure 6.3))* () between the balcony structure and () what is it called () and indoor () I think we talk about 150 millimetres here () that must ((name of a CEE)) be able to find out () so () then it doesn't matter so much how much insulation there is above and underneath
A: That is also what I think you have said before () I have also drawn it

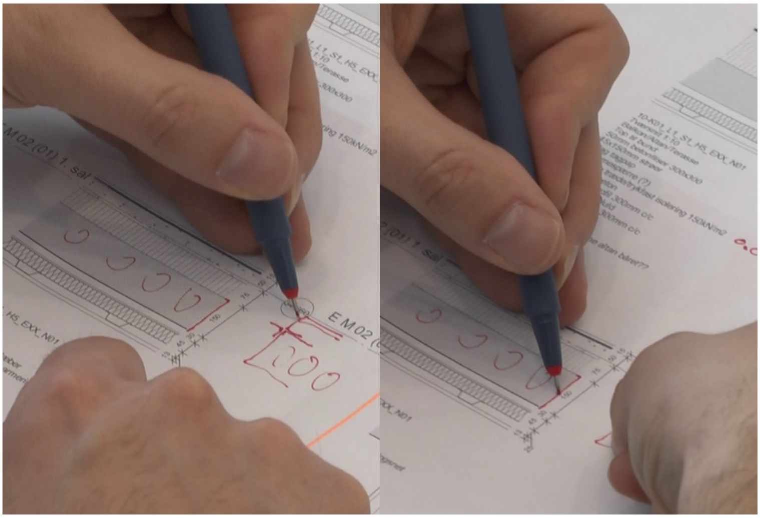

Figure 6.3: The energy specialist sketches on top of the printed detail drawing. The left picture shows how the energy consultant sketches another hollow core slab, indicating the floor construction inside the apartments. On top of the slab, he sketches flooring and window mountings. The right picture shows how the energy consultant point at the sides of the gap with the pen and his thumb.

The sequence of interaction described above shows how the printed drawing enables the energy consultant to draw on it. In this way, the energy consultant can convey the possibility of a gap between slab constructions in the floors to the other two designers. During his sketching, the energy consultant only draws a few things which are vital for his statement. He does not need to draw all details, such as materials in the flooring on top of the hollow core slab, the suspended ceiling hanging from the hollow core slab, or the mountings carrying the balcony floor. To illustrate the gap, he only draws a bit of flooring and some mountings which hold the window to show where the thermal envelope is placed. The energy consultant continues to sketch.

EC: It is crucial () it is crucial that we get () it is crucial that we get insulated in here *((draws, see figure 6.4))* () and similarly *((draws, see figure 6.4))* when we get on the outer side where it ends somewhere () that that

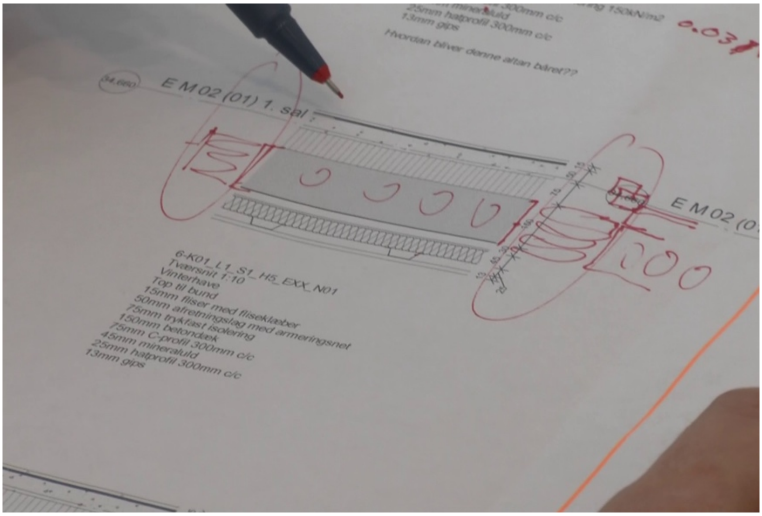

Figure 6.4: The picture shows how the energy specialist sketches curved lines indicating insulation and two circles around the areas with insulation.

CA1: That it gets a discontinuation
EC: Because we talk about 150 millimetres both places () It is vital that it goes through the constructions () but what happens over and under () that is mostly if anybody lets the window be open () that is not the situation we dimension for () we dimension after, I think, in winter there is closed () out here ((*points, see figure 6.5*)) and in a way also in here ((*points, see figure 6.5*))
A1: Yeah () okay

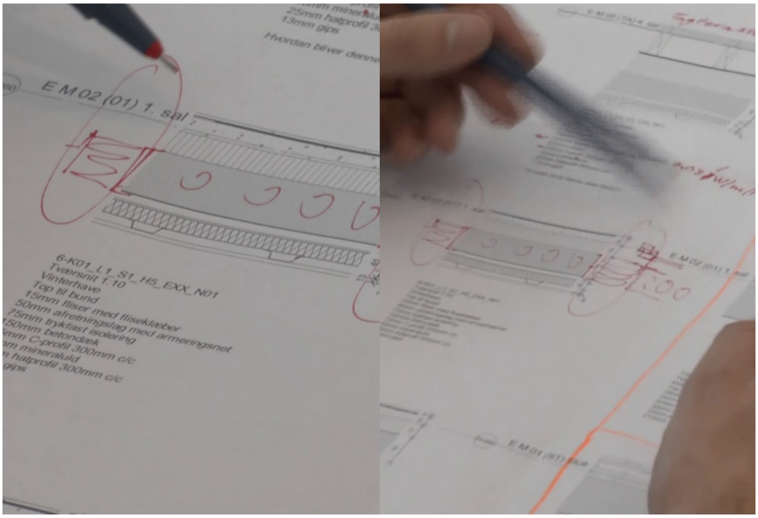

Figure 6.5: The left picture shows how the energy specialist points with his pen on the left side of the floor construction. The right picture shows how he points at the right side of the floor construction.

In the second sequence of interaction, the energy consultant highlights the importance of insulation in the two places by sketching, while he speaks, symbols illustrating insulation material as well as drawing two circles. He says that the thickness of the insulation should be 150 millimetres in both places. The sketch of the energy consultant has changed the printed detail drawing and added more to it. The simultaneous actions of the energy consultant, the pen, the printed detail drawing, and the sketch provide the architect and the construction architect with an idea about how the energy consultant wants the insulation to be designed.

AN ACT OF BETRAYAL

This section illustrates how the designers decide to go against the guideline specified by the energy consultant. The situation takes place at a weekly project meeting 25 May 2016. The same architect from the previous meeting presents the other designers with the specification given by the energy consultant.

A1: And then there is this one *((points, see figure 6.6))*

CEN: Yeah

A1: Those 150 millimetres of insulation that have to be there between the two slabs

CEN: Yeah () that is severe

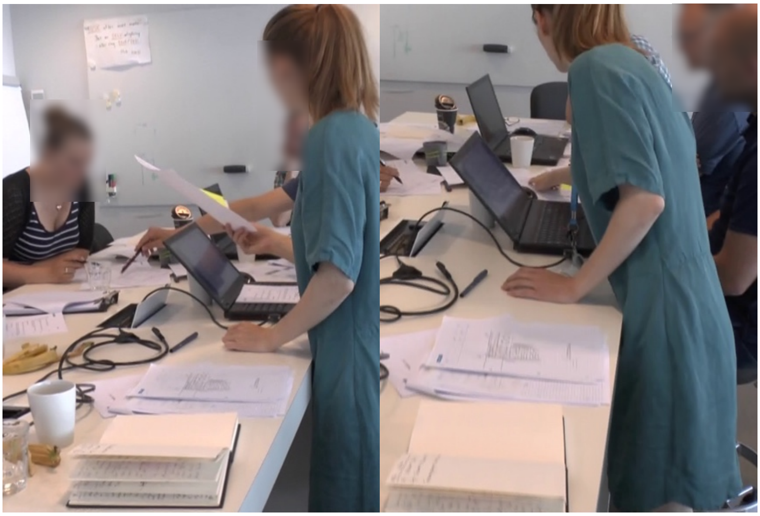

Figure 6.6: The left picture shows that the architect (to the right) finds a paper with a sketch on it. The right picture shows how the architect points at the sketch.

CA1: It is the whole door () that one we shrink a bit *((said with humour))*

((CA1 hands over the sketch to PM))

CEN: It was just (name of EC) who said how much there should be *((giggles))* () what he wanted to have there, right?

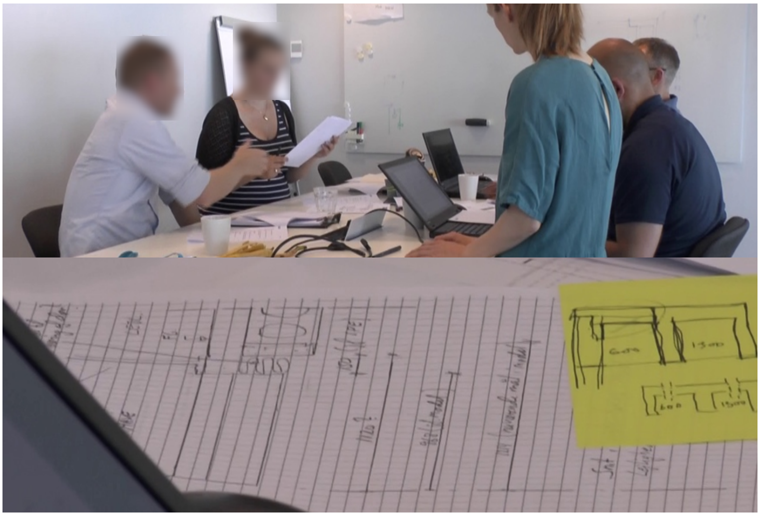

Figure 6.7: The top picture shows how the project manager reaches out for the sketch. The bottom picture shows the sketch. The sketch shows a hollow core slab, a balcony slab, and insulation placed between them. Underneath the insulation, it says: "150 (according to EC)."

A1: I had an idea that it would be 75 millimetres

CA1: That is probably also more realistic

((*brief pause in the conversation*))

PM: *((says in a low voice))* that one you just shrink a bit

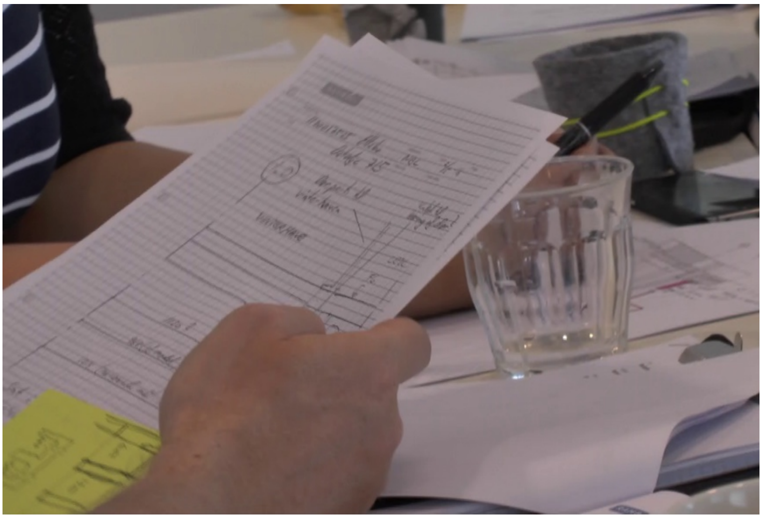

Figure 6.8: The picture shows how the project manager holds the sketch and looks at it.

The architect does not have to do much to show the other designers that the insulation requirement of 150 millimetres from the energy consultant is a 'bit too much' according to the designers. She presents them with a sketch drawn on a piece of paper, and the construction engineer looks at it and calls it 'severe'. The piece of paper allows the designers to hold the sketch and look at it up close. Even though the sketch does not show much, it indicates that insulation should be placed between a hollow core slab inside the apartment floors and a balcony slab. The construction engineer cautiously supports the interest of the energy consultant by stating that the energy consultant wants the specific amount of insulation. However, the thick insulation creates problems in the work of the architect and the construction architect when they have to draw the detail drawing. They argue that a reduced thickness of the insulation would be more 'realistic,' since it may fit better into the joint. The project manager accepts that they reduce the insulation thickness, even though the energy consultant has specified something else. The conversation continues.

> CEN: But does that mean that you change the location of that slab front edge?
> A1: Your slab front edge?
> CEN: Yeah, there *((points, see figure 6.9))* () that is why I want that detail done, right? () carrying the door and all that stuff () that there is at least what we talked with (name of EC) about last time and that was his requirement

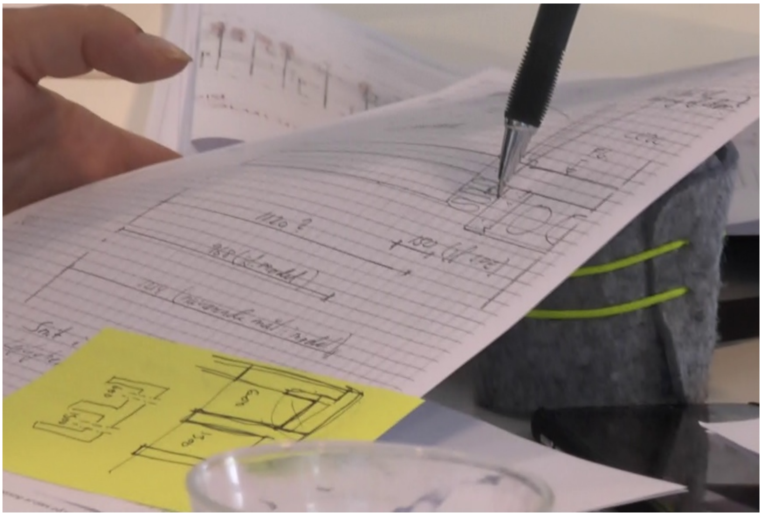

Figure 6.9: The picture shows how the construction engineer points with his pen at the sketch which the construction architect holds.

HPE: It is part of his energy framework calculation () and if you just shrink it without telling him then it does not consistent anymore
A2: How large an area are we talking about?
CEN: Yeah, that is the point
CA1: A door width
CEN: It is the whole area out to the winter garden, right?
A2: To all the winter gardens *((confirming))*
CEN: Yeah, just in the extension
CA1: Which is?

The construction engineer asks if the edge of the hollow core slab changes because of the insulation thickness changes. The question highlights how design features often are interrelated and change to one design feature may have an impact on several other features. In the interaction illustrated above, the designers begin to examine the issue related to the insulation. In the following sequence, a plumbing engineer stresses the importance of telling the energy consultant about the change insulation thickness. The plumbing engineer is certified in making energy labels and makes energy labels in other projects for the engineering consultancy company.

HPE: It is not sure that it is significant for the final framework () but that framework must be documented that it is correct through an energy label () and such a thing like that one () if it was a person like me that was told to do an energy label () it would be such a thing I would feed on () it is the place where the pain is () all that whether it is one type of window or the other type of window and how much ventilation that runs, it does not matter () it is probably consistent () but such details with how the things get joined () it would be such places I would go and fiddle () it would be there I would find the mistakes () all the rest I would not care about honestly () so, it should be corrected-
PM: But those 150-
A2: That which does not give value () like gives value overall () is insignificant?
HPE: Yeah () basically
A2: The trifles are important
HPE: Because that which gives the value is there where people already have focused () and the task for the person who should do the energy label is not to figure out whether () I mean () it is to figure out whether it is correctly done compared to the energy framework

> PM: Those insulation thicknesses which (name of EC) has introduced they must have been adjusted a bit since () because they are some he introduced some time ago, right? () So, challenge him a bit on () if we cannot screw it together-
> A1: There is that rule about looking at what the total U-value is () (name of EC) has outlined some elements which have a U-value which is under what the requirements are for the buildings to maybe be able to cope with places where we cannot entirely get the amount of insulation in we need () He is aware that there will be places where
> PM: Yeah () he has to be challenged a bit () then challenge him on it () but at least get it drawn so we are sure what it looks like

The project manager suggests that the specification for insulation may be 'old' and that the energy consultant might have a new idea of the importance of the insulation. The arguments put forth by the architect and the project manager go against the interest of keeping the 150 millimetres of insulation. They want to challenge the energy consultant. The conversation ends, and the project manager has accepted that the designers continue with a reduced amount of insulation for the specific joint.

After the meeting, the construction engineer finds a detail drawing illustrating the joint the designers had been discussing. The drawing illustrates 75 millimetres of insulation as agreed upon at the previous meeting, and not the 150 millimetres specified by the energy consultant. The construction engineer remembers that the energy consultant has specified the 150 millimetres of insulation and wants to make sure that the energy consultant knows about the change to the detail drawing. He decides to write an email to the energy consultant. With the email, the construction engineer attaches a detail drawing with the 75 millimetres of insulation so that the energy consultant can see the drawing. In an interview, the construction engineer says:

> *"I just wanted to make sure that everybody around the table agreed that now it is the 75 and not the 150 which he had said earlier. So, I just wanted confirmation from (name of the energy consultant). That is why I called it into question. Is it discussed with (name of the energy consultant)? And does he agree? It was just so I do not have to correct something and then later correct it again." (the construction engineer who is responsible for designing constructions in the new building part)*

The energy consultant reads the email and asks the construction engineer and the architect from the previous meetings to join him for a meeting. At the meeting, the three designers discuss the detail drawing and, according to the architect, the energy consultant did not accept the change from 150 to 75 millimetres of insulation.

> *"We had actually reduced it to 75. We had been a bit perky and it went really fast. And then he came afterwards and said, 'hey, what have you done here?' And then we asked if it could be possible with the 75 millimetres of insulation between these two hollow core slabs? Then he said, 'no, it is not possible. It should be 150 millimetres of insulation there.' Then we had to revise the drawings." (the architect who makes detail drawings and section drawings)*

After the meeting with the energy consultant, the architect is forced to correct the detail drawing, so the construction joint includes 150 millimetres of insulation and not only 75 millimetres.

FAILED ATTEMPT TO REDUCE INSULATION

This example shows how the energy consultant explains to an architect and a construction architect the importance of thermal bridge insulation – the energy consultant sketch on top of a printed detail drawing to illustrate his point. The detail drawing, his sketch, and his words constitute the message that insulation should be placed in two crucial places and have a thickness of 150 millimetres each. By sketching instead of only telling the other designers how it should be, the energy consultant visualises his intention of reducing thermal bridges and how the designers can help him achieve this aim. However, as seen in the subsequent meeting, the designers go against his interests and want to 'challenge' him on his specifications. A sketch of the joint between constructions changes hands during the meeting as designers look at the insulation specification. The decision to reduce the insulation helps the designers to draw the joint between constructions because many other requirements take up space in a relatively small area. Other requirements could be transitions between different types of flooring, mountings to hold large and heavy windows above and under the joint, fire protection of constructions, as well as issues relating to airtightness of the building envelope. After finding out that the designers have drawn thinner insulation than specified, the energy consultant requires the architect to correct the detail drawing to fit his original specification.

The sketch made by the energy consultant at the first meeting visualises how he imagines the thermal insulation of the joint, and at the same time, the sketch enables the architect and the construction architect to follow his advice. The sketch shows where the insulation should be placed, and the energy consultant states that it should go through the slabs and be 150 millimetres thick. The interaction enables them to act on the specification. However, other requirements hold them back. They find it difficult to design the joint with 150 millimetres of insulation and confer with the other designers about reducing the insulation thickness. The architect and the construction architect convince the others about reducing the insulation thickness, but the energy consultant will not accept it and reinforces his interest in the 150 millimetres of insulation. The example shows how design features go through ‘trials of strength’ (Latour 1987) during building designs. The specification lost its battle to other requirements when the designers decided to reduce the thickness, but rose again when the energy consultant reinforced the original specification.

The next section presents the negotiations around an issue concerning basement insulation.

BASEMENT INSULATION & HESITATION

This example sheds light on situations where the designers become uncertain about how to insulate the basements. The uncertainty spread when the designers have no drawings or documents stating how the basements should be insulated. When discussions remain verbal, doubt appears among the designers, and they want to make sure which intentions the energy consultant has with the basements. The empirical example also shows how the same designers stop hesitating and being in doubt when the design of basement insulation starts to become part of material objects. The example shows the transition from uncertainty, doubt and questions to more certainty, less doubt and fewer questions.

The energy consultant is regarded as a 'specialist' in the engineering consultancy company and does for that reason not attend all project meetings during the energy renovation projects (see chapter 4, The Case, for a description of the role of 'specialists'). The energy consultant, in this way, is absent during most of the project meetings. Nevertheless, the energy consultant provides the other designers with guidelines to how the building design can comply with the energy requirements. The designers are also able to reach the energy consultant in the office building or by phone or email. However, the absence of the energy consultant creates problems in the project. Since the energy consultant is absent, the designers have to handle energy-related issues by themselves. The present empirical example shows how discussions about the thermal insulation of the basements turn up several times during the six weeks of observations. In each situation, the designers try to figure out how to handle the thermal insulation of the basements and how the energy consultant might want to have the insulation designed.

This section presents four situations in which the designers discuss basement insulation. The situations show how the designers try to figure out how to deal with the design feature. The first and second situations show how the designers, throughout the four weeks, continue to discuss the basement insulation. Even though some of the designers show signs of certainty, the design feature of basement insulation is in both situations put into question. The third and fourth situations describe how the designers begin to involve themselves with material objects which gradually stabilises the design feature. Questions about the basement insulation begin to become closed.

OPPOSING STATEMENTS & CONFUSION

This section illustrates two situations in which the designers become uncertain and doubtful about how to design basement insulation. Even if some of the designers seem to know how the thermal insulation for the basement should be designed, design team members still end up being uncertain about what the energy consultant expects and what he has said previously. The two situations happen within four weeks. During this time, the basement insulation has not been drawn into the project material, and uncertainty reappears in the second situation. In both situations, the designers gather to a weekly project meeting to coordinate the on-going design tasks.

In the first situation, a construction engineer asks approximately 45 minutes into the meeting, the project manager about the basement insulation. Before he asks, he looks at the section drawing illustrated on the TV screen. It seems that the section drawing inspires him to ask the question.

> CEE: *((leans over the table, see figure 6.10))* There will be insulated between the first floor and the basement, right? () The basement is cold, right?
> PM: The basement is cold, yes () the starting point was () that () the slab () between the first floor and the basement should be () re-insulated
> CEE: Yeah () from below?
> PM: From below, yeah

Figure 6.10: The picture shows how a construction engineer (in the left top corner) leans over the table and asks the project manager (to the engineer's left side) a question.

CA1: What about the pipework? *((turns her attention to VE))*

((VE shrugs, see figure 6.11))

PM: The pipework () runs inside () the low basement today () and in the low basements-

CA1: There is-

PM: There is already insulation () so () it is the same we should do out in () in the rest of the basement

Figure 6.11: The picture shows how the ventilation engineer (sits by the laptop) shrugs.

The interaction gets initiated by the construction engineer, but it seems that he asks his question because he sees the section drawing on the TV screen and wonders where the insulation should be placed. Even though the designers do not interact directly with the digital section drawing, the drawing still 'guides' their discussion by leading their attention towards the basement. The question raised by the construction engineer raises a new question from the project manager.

PM: It is also vital *((turns his attention to PA))* that we get hold of (name of EC) () to hear with him () is this necessary () or is it not necessary () to meet the energy requirements?

PA: We should ask (name of EC)

CA1: Yeah () we talked with him yesterday, and there he was () what is it called () we talked at least about a warm basement, didn't we? *((turns her attention to A1))*

A1: Yeah ()

CA1: Yeah

A1: Not () under the first-floor slab, but around *((moves her arm, see figure 6.12))*

Figure 6.12: The pictures show how the architect moves her arm in a circular motion in front of her.

CEE: Isn't only in the 'extension' part?

CA1: The existing basements are not warm () we do not construct façade down in front

A1: Ah, okay

CA1: We should probably () we will bring it by (name of EC)

PA: Is it () is it? *((turns her attention to A1))*

A1: Yeah, yeah () I will do it

The designers end their conversation about the basements, and after a few seconds, they turn their attention towards a new topic. In the interaction illustrated above, the architect questions the statements made by the construction architect, the project manager and the construction engineer. According to the architect, the energy consultant wants the insulation to go around the building instead of being placed on the ceiling in the basements. She highlights her point by moving her hand. Because the statement made by the architect opposes the statements of the other designers, the designers hesitate and want to make sure which design option is the 'right' one, according to the energy consultant. Even though the interaction remains mostly verbal, the section drawing still 'acts' by inspiring the construction engineer to ask his question. Furthermore, the hand movement made by the architect can be seen as a way to support her claim about how the insulation should be designed.

The second situation happens four weeks later. Approximately 20 minutes into the meeting, an architect asks the other designers about a question concerning insulation of the plinths[4].

> A3: *((reads from his paper))* There is something about that we () on plinths attach 250 millimetres of insulation this should go under prime contract B *((stops reading aloud))* have I written () and it is because I doubt who describes re-insulation of plinths? () because I have the closing of facades, that is, it is also a little bit a closing of the façade but () we are under the ground, and we are a little over the ground () and, yeah () so, the question is whom does it belong to? () me or somebody else?
> *((A1 finds a printout of a section drawing, see figure 6.13))*

Figure 6.13: The pictures show how an architect finds a section drawing and turns it around.

The question asked by one architect immediately triggers another architect to find a printed section drawing. The second architect knows where in the building design the first architect refers and opens the section drawing so that the meeting participants can see the basement in the section drawing. The second architect finds the drawing

[4] Plinths are the base of the outer walls. In the energy renovation project, the outer walls of the basements go approximately one meter above ground. The basement walls, therefore, consist of one part under terrain and one part above terrain. The part above terrain, the designers call the 'plinth'.

instinctively and without hesitation. In the subsequent interaction, the printed section drawing becomes the focus of attention for the designers several times.

VE: Where is it?

A2: Is it the 'extension'?

A3: It is just () we have such half high basements () as I remember

A2: Yes

PA: The existing should not be re-insulated () there we insulate down here *((points, see figure 6.14))* () from underneath

PM: And that we have 'cleared' with (name of EC)?

A3: Is it parked another place than in-? () it is just because () it is not in your honour, it is in my honour that I have written this and thought, er, is it one that I have or what?

A2: We do not do anything out here *((points, see figure 6.14))* well

PA: It is just as much about

A2: That which is visible is going to be painted () and nothing more

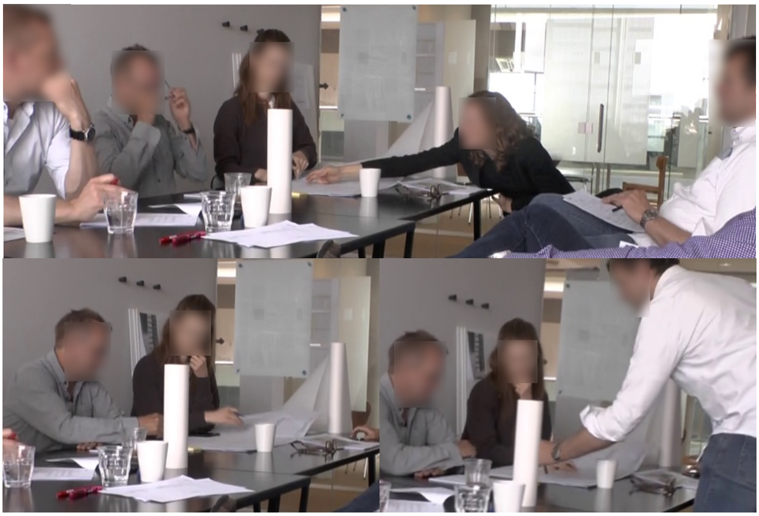

Figure 6.14: The top picture shows how the project architect reaches over the table to point at the printed drawing. The bottom left picture shows how another architect (to the left) points at the same drawing. The bottom right picture shows how a third architect stands up to point at the printed drawing.

A3: Yeah () I am going around and think that I shall write down to here *((points, see figure 6.14))* () so, I haven't written anything about underneath here *((points, see figure 6.15))* and down here *((points, see figure 6.15))*

PA: Good

A3: Good () just so I know

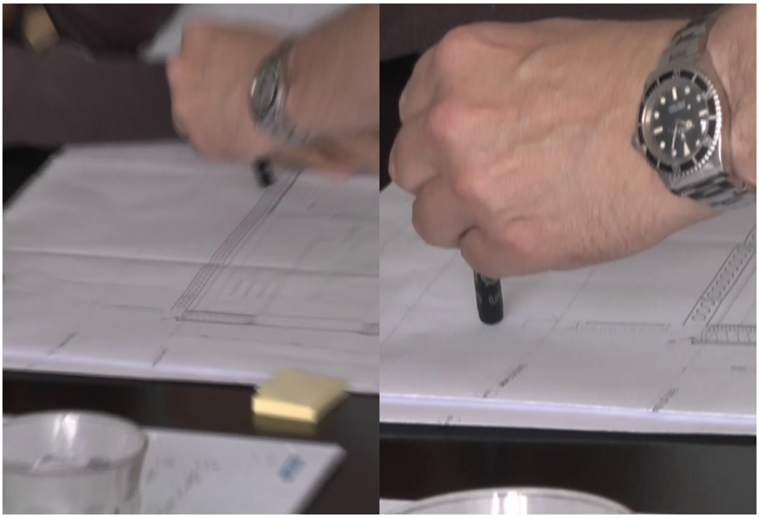

Figure 6.15: The left picture shows how an architect points at the underside of the first-floor slab by moving his pen along the slab. The right picture shows how the architect moves his pen over the outer wall of the basement.

The designers take turns to say a statement and point at the section drawing. The simultaneous speech and pointing underline their statements, and their statements do not make sense without the one or the other. The project architect indicates the floor constructions between first floor and basements by pointing at 'down here'. In this way, she states that the basements should have insulation on the ceiling. The second architect underlines that they are not planning to do 'anything' to the outer walls by pointing at the location on the drawing ('out here'). The first architect then makes a three-step argument and points while he says that he only describes the façade going down to the basement ('down to here'), and he does not describe the insulation underneath the floor constructions ('underneath here') and neither the basement outer walls ('down here').

VE: It is just underneath the slab () the basement slab?

PM: Yeah *((points, see figure 6.16))* () we should have it 'cleared' with (name of EC) to be totally sure that () that it-

PA: It is not something new () it has been like that the whole time

PM: Yeah, yeah, it has

PA: The only thing where there is a question is that in the 'extension' () there we have another situation () as I recall, it is a warm basement there

PM: On the basement walls

A1: Yeah *((looks into her papers, see figure 6.16))*

PM: Yeah

PA: So, there is something there

A3: Painting of plinths and inspection of plinths will then become a part of prime contract B?

A2: It is outdoor, we will figure it out

PA: There is a () a challenge concerning the fact that the 'extension' shall have a warm basement () why does it have that?

A1: It has- () yes

PM: Yeah, it makes it complicated

A1: Yeah () now I say *((turns her attention towards the section drawing on the table))* something opposite of what you have said () I think (name of EC) has talked something about that there should be insulated out here *((points at section drawing, see figure 6.16))*

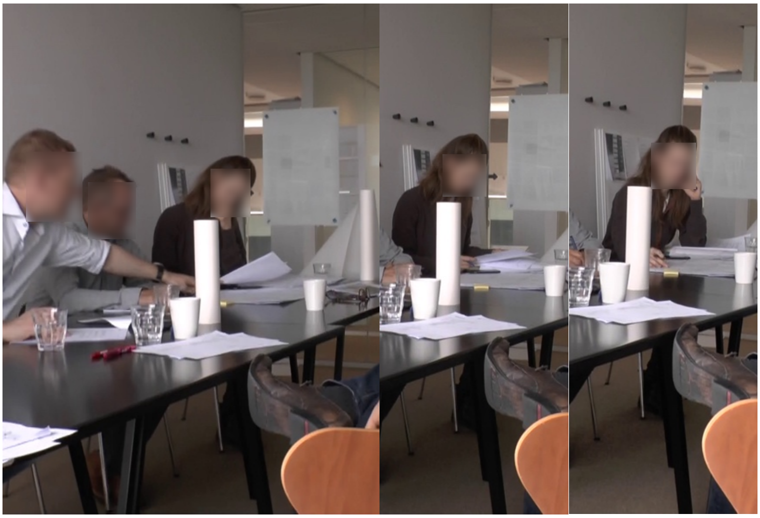

Figure 6.16: The left picture shows how the project manager (to the left) reaches over to point at the drawing. The two pictures to the right show how an architect looks into her papers and then points at the printed drawing.

PM: Can you talk with (name of EC)?

PA: Can you discuss it with him?

A1: Yeah () I will () because with those typical building components I deliberately did not draw anything underneath the first-floor slab, because there should be insulated all the way around

PA: It is only the 'extension' there should have it

A1: Okay

((The designers end the discussion and A3 turns their attention to another issue))

Similar to the first meeting, the third architect says an opposing statement to the statements of the other designers. Furthermore, she refers to her previous talk with the energy consultant. The energy consultant is not present to say which one is the 'correct' solution, so the designers hesitate once more. The situation is similar to the first one in regards to confusion around the location of insulation, even though the project has moved forward four weeks in time. Before the third architect contradicts the other designers, she looks into her papers to see if she can find any information about the basement insulation, but without any luck.

The two situations show how the energy consultant fails to 'act on a distance' (Latour, 1987) because there are no inscriptions to 'hold the place' (Latour, 1988) for him. The energy consultant is absent from the meetings and no drawings or texts 'speak on his behalf.' The project manager, the construction engineer, the project architect, and the construction architect all state how they believe the basements should be insulated. The architect contradicts them twice which creates doubt among the designers. Both statements might be 'true,' however, the designers do not know for sure. In the examples, two drawings draw the attention of the designers towards them: A digital section drawing shown on a TV screen and a printed section drawing placed on a table. Both section drawings are treated as 'intermediaries' by the designers in the way that the drawings become 'reference points' to which design features are currently known and agreed-upon in the design process. In the example with the printed section drawing, the relations between designer, drawing, place on drawing, and the verbal statements are vital in presenting what they know or what they propose to address the design of basement insulation.

THE MATERIALISATION OF INSULATION

This section shows how the designers begin to materialise basement insulation into material objects. The transition from abstract, verbal discussions (as shown in the previous section) to tangible, concrete objects makes the designers relate to basement insulation in another way. Their knowledge about basement insulation and their discussions change through the interaction with material objects. This section illustrates two situations in which the designers engage with material objects in order to solve the issue regarding insulation of the basements. The interaction between designers and material objects enables the establishment of the basement insulation in the project design. In the first situation, the designers gather to a design meeting 20 May 2016. The designers discuss a section drawing when an architect asks a construction engineer a question.

> A1: (Name of CE), there is also something about insulation of the basement () is it () the outer walls *((points, see figure 6.17))* that is going to be insulated?

Figure 6.17: The picture shows how the architect points at the outer wall of a basement in a section drawing.

CEN: Yes, it is a warm basement in ‘extension’

A1: Then here? *((sketches, see figure 6.18))*

CA1: Where does the insulation lie? () on the outside?

CEN: No, outside () on the outside *((A1 crosses her lines over, see figure 6.18))*

A1: All right, outside *((sketches, see figure 6.18))*

CEN: 25 centimetres on the outside ()

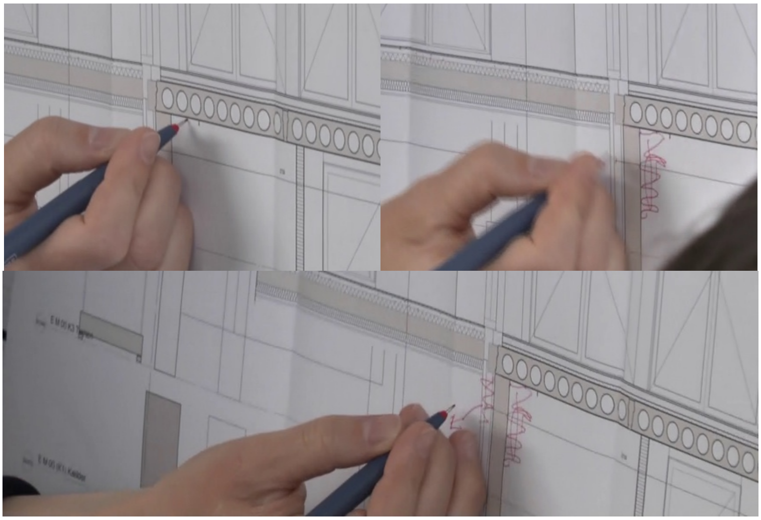

Figure 6.18: The top left picture shows how the architect begins to sketch on the printed drawing. The top right picture shows how the architect tries to erase her line by crossing out the line. The bottom picture shows how the architect sketches insulation to be placed on the outside of the outer basement walls.

In the conversation, the designers take the insulation of the basement in the extension for granted. They no longer question if there should be insulation or not. At a previous meeting, the construction engineer told the other designers that there should be insulation on outer walls of the new basement for the extension. The construction engineer told the others that he would talk with the energy consultant and perhaps they could agree on placing 250 millimetres of insulation on the outside of the walls. The architect refers to this conversation when she asks the question at the beginning of the interaction described above. At the present meeting, the designers do not question whether to have insulation, but instead, they question where the insulation should be placed.

The interaction also shows that the insulation is not drawn into the section drawing. The architect begins to sketch insulation at the inner side of the outer walls, but the construction engineer stops her. The insulation should be, according to the construction engineer, placed on the outside of the walls. A construction architect hints that the insulation should be placed outside by questioning the sketch which the architect began to draw. The architect "erases" the first lines by crossing them over and draws new lines, but, as the next sequence of interaction shows, the construction engineer stops her again.

CEN: But not up there () where you, of course, have façade () so

CEE: It is not until down in terrain

CEN: Down in terrain. Down in terrain, right?

A1: No, we do not have façade () oh () how do we do with new building there?

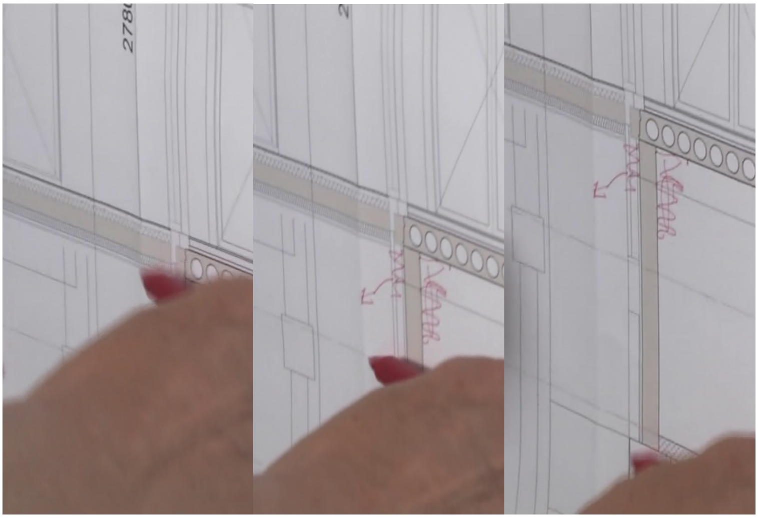

Figure 6.19: The pictures show how the construction engineer points at the drawing while he speaks. He moves his pen from the point at the left picture to the point in the picture in the middle. Then he moves his pen from the point in the middle picture to the point in the right picture.

CEN: There you make some façade down underneath here, right? () you make some façade here *((points, see figure 6.19))* () down to terrain () then I have basement insulation from terrain and down

((The architect writes notes on the drawing, see figure 6.20))

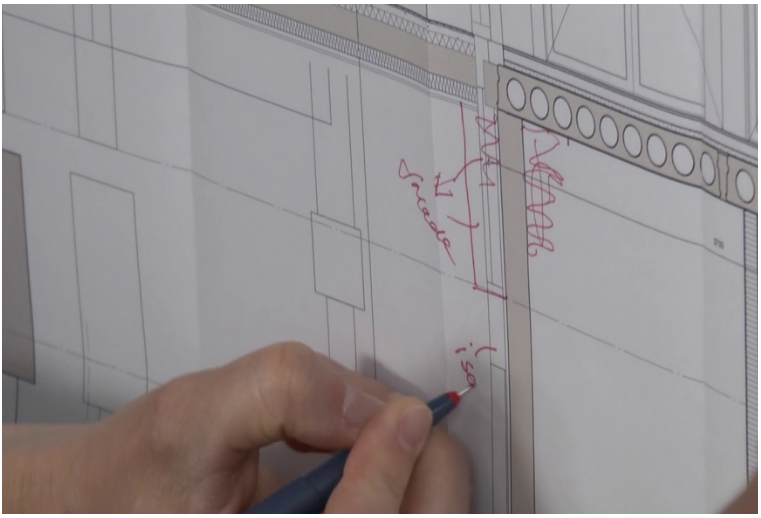

Figure 6.20: The picture shows how the architect draws a box and writes "façade" and then writes underneath "iso" as an abbreviation for insulation.

The interaction described above shows how the basement insulation begins to become materialised into the drawings. The sketch made by the architect is a step towards the 'fixing' of the basement insulation. Before the meeting, the basement insulation was not drawn in the section drawing and, as shown in the previous section, the designers discuss the location of the insulation. The gradual fixing of the basement insulation involves sketching activities, but first when the designers agree on the location of the insulation. The designers do not question insulation for the new basement any longer.

The following sequence of interaction shows another kind of interaction with material objects. This time, the designers do not focus on sketching activities but instead discuss basement insulation verbally concerning a specific object. In this situation, the designers meet at a weekly project meeting 25 May 2016 to coordinate the design tasks at hand. Once more the basement insulation is brought up as a topic of discussion.

A1: Do you have () (name of CEN), do you have clarified with (name of EC) if there shall be () a warm basement?

CEN: No, that I should not

PM: No, it was-

CEN: It was decided that it was a warm basement on the meeting last Friday

A1: Yeah

PM: Yes, it did

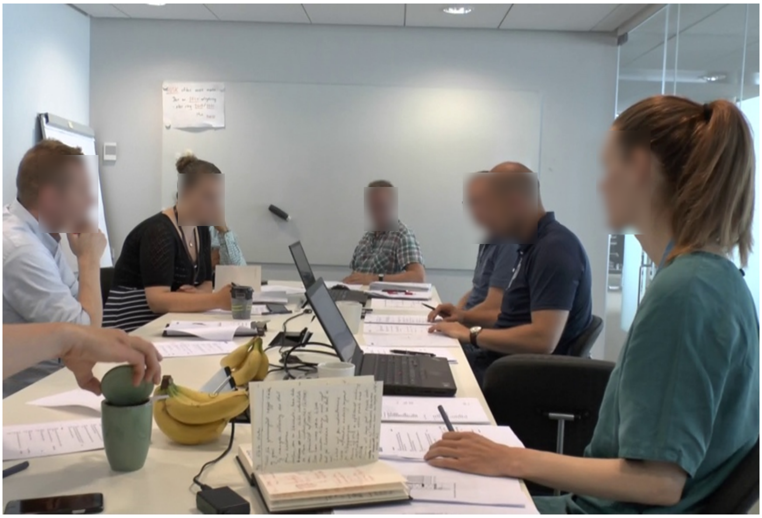

Figure 6.21: The picture shows the meeting set-up. The person to the far right is the architect asking the construction engineer who sits second to her right. The project manager sits at the far left holding his chin and the construction architect next to him.

CA1: *((Addresses PM))* and it was also decided () where it was? () if it was in the façade or the slab, right?

PM: Yeah () you can say that () there are two scenarios () you might say () the renovation part () where it will be placed underneath the slab, and that is also something, among other things, you should grab hold of (name of EC) about, what he has considered there-

A1: There is no () I have talked with (name of EC) about it, there is no heating of () the existing () that stands as it is () he leaves it as it is () there is nothing there () but new build must

PM: Yeah, okay, so there is nothing on the underside of the slab in the basement in the renovation ((part of the project))?

A1: No

CA1: Not () not as his requirements

The construction engineer and the project manager take the insulation of the new basement for granted, fixed, not open for changes. They respond strongly to the question of the architect which from the outset seems to question the design feature which they regard as 'locked.' However, according to the project manager, there is still a question about how much the existing basements should be insulated. This design feature, according to him, remains open. The designers leave the topic of the new basement and continue discussing insulation of the existing basements.

> CEN: Should there not be more insulation than there is today?
>
> A1: Not according to () that is, I wrote to (name of EC) () last Wednesday, and then I got an answer today that we do not do anything with the existing () but it is only new build where we do something
>
> PM: That is () that is only positive
>
> E: Do we keep the energy framework?[5]
>
> PM: We have to do it () it is (name of EC) that has been responsible for the energy framework
>
> A1: Yeah () that energy framework report that he has made for () one month, one and a half month ago, but I have just not heard anything
>
> PM: No () I talked with him about whether there should be insulation underneath the slab
>
> A1: Yeah, but that there is now, right? () As said, there is some
>
> PM: There is a little, sporadically in towards the low basement
>
> A1: Yeah
>
> PM: That is the only thing () but it is not () consistent all the way through
>
> A1: No, okay

The architect refers to an email she has received from the energy consultant. Even though she has received the email with a delay, the email describes how the energy consultant wants the basements to be insulated. The project manager accepts the proposition given by the energy consultant but mediated through the email and the architect.

The architect mentions the delay in response time from the energy consultant as well as the energy framework report which she has not yet seen. In this situation, it seems to frustrate the architect that the energy consultant is absent from the project. The design team is approaching the deadline which is at this time scheduled to June 2016, only a few weeks from the present meeting. The time pressure makes decisions such as basement insulation important if the designers should be able to incorporate it into the building design. In this way, the email and the report are crucial 'mediators,' because the energy consultant is absent. The last sequence of interaction underneath shows that the designers are ending the discussion regarding basement insulation.

[5] 'E' represents an engineer who has not been present at any other observed meeting. The engineer seems to be making a quality assurance of the project management of the energy renovation project.

PM: So () but I think that it is only positive really () then we have little freer reins
HPE: Well, in the whole low basement, there is insulation up against the floor
CA1: Yeah
A1: Yeah
PM: Is it like that all the places all the way through?
HPE: Yeah () I have been all the way through, all four blocks () so, it does
PM: Fine

This section illustrates how the basement insulation becomes materialised in objects, such as section drawings and emails and how the materialisation process gradually stabilises the design of insulation for the existing and new basements. Even though the designers still question some aspects of the design, they simultaneously regard other areas for 'locked' or 'fixed.' In the first situation, the designers know that the basement insulation should be placed on the outer walls. This is given. The question then becomes where it should be placed. The location of the insulation is established through interaction between the designers and the section drawing. The same location is guaranteed by the project manager and the construction engineer in the next meeting. They still regard the insulation for 'agreed' and therefore 'locked.' In regards to existing basements, an email from the energy consultant 'locks,' for the time being, the basement insulation in this part of the building design. According to the architect, they should not do anything to the existing basements in regards to insulation. The email enables the architect to talk about the intentions of the energy consultant in a convincingly way.

LACK OF INSCRIPTIONS

This empirical example illustrates how the designers hesitate, stumble, and become uncertain when there are no 'inscriptions' (Latour, 1987) to support the claims of the energy consultant. The designers want to design the buildings according to the energy consultant's recommendations; however, when they cannot agree on what the recommendations are, they are left with doubt and questions. The empirical example also shows how acts of sketching and receiving emails support the stabilisation of basement insulation. The designers sketch insulation for the new building into a section drawing, and the location of the insulation is re-established in a meeting a few days later. The insulation for the new basements is in this way being considered as 'locked' or 'frozen' (Whyte et al., 2007) by the designers. The email stabilises the design of insulation for the existing basements by stating the intentions of the energy consultant. The architect presents the design of insulation for the existing basements as 'frozen.'

The situations illustrate how difficult it is to 'act on a distance' (Latour, 1987) for the energy consultant. The energy consultant is forced by the company structure to work on several projects at a time and cannot spend much time on the energy renovation project. With this constraint, the energy consultant attempts to guide the designers in the project as well as he can. Even though his attention might have been conveyed verbally among the designers, the illustrated situations show how the designers still hesitate and doubt his requirements. This study suggests that the role of material objects, in this case, the section drawing and email, is important in keeping the intentions of the energy consultant in the project while he remains absent. The sketching activity and the email both help the designers stabilise the design feature. In this way, material objects can be the 'lieutenants' (Latour, 1988) of the energy consultant and keep his interests 'in place.'

The next section presents the negotiations around floor constructions and insulation for floor heating systems.

RE-DESIGNING FLOOR CONSTRUCTIONS

This example concerns the making, unmaking and re-making of the design of floor constructions with floor heating. It shows how already-agreed-upon design features may become subject to scrutiny and questioned once more because engagements with material objects give the designers new insights into the building design. In this way, the empirical example shows how the materiality of objects may temporarily stabilise design features, but also open them up and make them amenable to work further.

Floor heating is part of the heating system of the buildings, and the use of floor heating contributes to the buildings' energy consumption. The client has decided to install hydronic floor heating in bathroom floors by installing heating tubes in concrete flooring. One design feature which takes up the attention of the designers concerning the floor heating is the specifications for insulation. The purpose of the insulation is to prevent the floor heating in heating downwards. Floor heating is placed in floor constructions separating apartments. If the floor constructions do not have a layer of insulation underneath the floor heating tubes, the floor heating might warm downwards into the apartment of the downstairs neighbour. However, space in the floor constructions is limited because of design constraints, and the designers find it difficult to find the required space for the insulation. This example follows how the issue appears for the designers and how they try to solve it.

KNOWING THROUGH DRAWING ACTIVITY

One of the designers, an architect, works on specifying what the project participants call 'common constructions.' These are a collection of detail drawings in the scale of 1:5 depicting the material layers in the most common constructions in the project. The detail drawings show a small section through constructions such as walls, floors, or roofs. Each construction is illustrated with lines and hatching indicating layers of material and a text describing the characteristics of the materials (see figure 6.22). The energy renovation project involves different versions of constructions depending on where in the building design the construction is located. For example, inner walls do not need as much insulation as outer walls which make up the thermal envelope. The designers gather the most common variations in the collection of detail drawings.

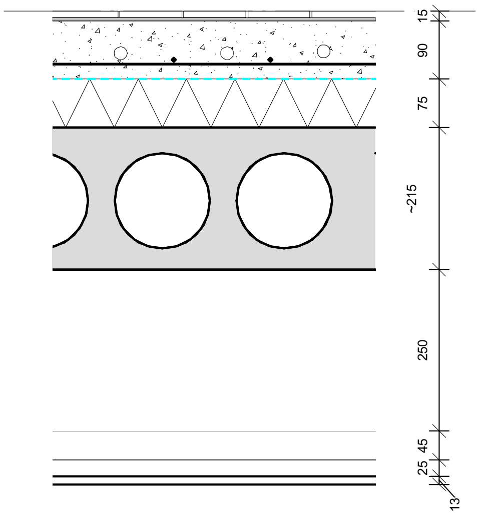

Figure 6.22: The picture shows a detail drawing of a 'common construction,' in this case, a floor construction between bathrooms. The construction layers in the drawing are from the top: 15 mm tiles, 90 mm of concrete with floor heating tubes, 75 mm of insulation, 215 mm of hollow core slab, 250 mm space, 45 and 25 mm for the construction that holds the ceiling, and 13 mm for plasterboard as the ceiling. Between the insulation and the concrete, the designers place a membrane to avoid that concrete goes through the gaps between insulation mats.

From February to April 2016, the architect works on detail drawings of 'common constructions.' In the case of each construction, the architect has to make sure that the construction complies with building regulations concerning, among other things, fire protection, acoustics, and thermal insulation. She also has to make sure that the constructions meet the aesthetic preferences of the client as well as the financial constraints of the project budget. Even though the architect works on these detail drawings, she is not alone to ensure that the constructions live up to all these requirements. The development of the constructions is a continuous dialogue between the designers, the client, building regulations, external consultants, and changes to project budget. As the project develops, changes may very well occur to the constructions. The focus of this empirical example is on floor constructions with floor heating, because, later in the process, the designers figure out a problem relating to the height of the floors. However, while the architect works with the detail drawings of the constructions, she is not aware of the issue.

The following situation illustrates how the architect presents the design of a floor construction to the energy consultant and how the energy consultant responds to the detail drawing. The situation takes place during a meeting 19 April 2016, where the architect has invited the energy consultant to discuss specification of insulation in the common constructions. First, the architect presents floor construction with floor heating. Subsequently, the energy consultant provides the architect with specifications for insulation in floors with floor heating.

> A1: And then when there are such underfloor heating pipes () that is such an absolute ((height)) where I just look at DBRI[6], right? *((draws a line, see figure 6.23))* Where there is *((points, see figure 6.23))* such a mesh reinforcement
>
> EC: Yeah
>
> A1: And then there are those underfloor heating pipes, and then there is
>
> EC: Then there is parquet flooring?
>
> A1: Yeah, they become casted into the concrete
>
> EC: Yeah

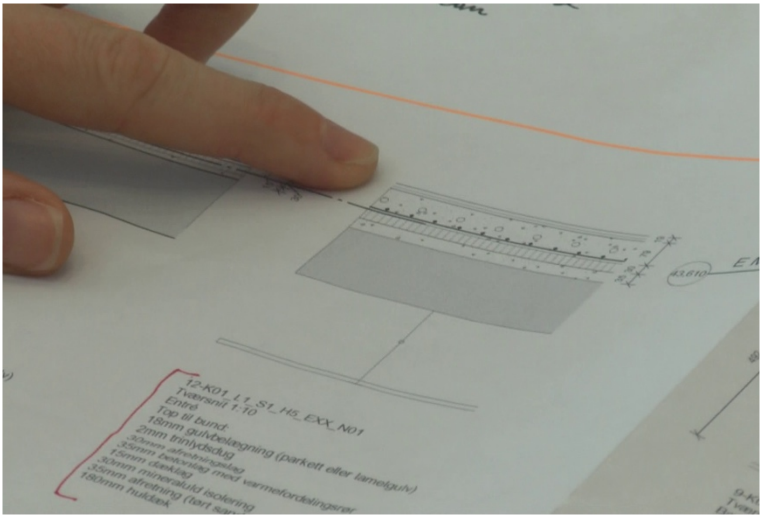

Figure 6.23: The picture shows how the architect has drawn a line next to the text underneath the detail drawing and that she points at the mesh reinforcement which is placed in the concrete layer in the drawing.

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[6] Instructions from the Danish Building Research Institute

The architect treats the floor construction as 'black boxed' by transferring information from an instruction written by the Danish Building Research Institute without questioning it. The Danish Building Research Institute[7] provides guidelines for building professionals in how to plan, construct and maintain buildings based on research. In the illustrated situation, the architect has found a description of a concrete flooring with floor heating tubes and drawn the detail drawing according to the description. The architect and the energy consultant do not question the floor construction drawn by the architect. In the following sequence, the energy consultant presents specifications for insulation concerning the detail drawing.

> EC: At places where there is floor heating () there must be, as said earlier, a certain degree of insulation () from the tubes *((points, see figure 6.24))* and downwards () yeah, if it is okay to use EPS () this 0.031 () then we can manage with 30 millimetres () as long as there is () usually you say 50 millimetres of insulation () but if you take () if there is a little build-up downwards here () which you can include in the calculation

Figure 6.24: The picture shows how the energy consultant points at the drawing.

[7] For more information, visit www.sbi.dk/en

CA1: Build-up downwards?

EC: *((giggles))* yeah, "build-down" () there is suspended ceiling here for example () it also gives some insulation, then we also start to look at that the hollow core slab also gives some insulation () and stuff like that () and then we can manage with 30 millimetres EPS () we can manage with 40 millimetres of glass wool or 30 millimetres of the good EPS

((A1 starts to write, see text at figure 6.25))

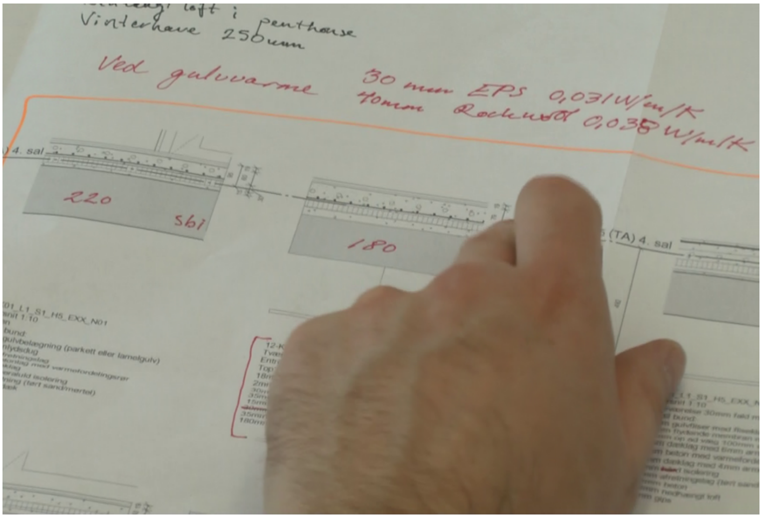

Figure 6.25: The picture shows how the architect has written the text in red above the hand of the energy consultant. The text says: "In regards to floor heating: 30 mm EPS 0.031 W/m/K, 40 mm mineral wool 0.038 W/m/K."

A1: With floor heating, right?

EC: Yeah () when you make the overall estimation and say if the insulation should manage it all by itself and if it is glass wool () then it is 50 millimetres normally () if we calculate precisely because we need the space then we might manage with 40 millimetres () or we can manage with 40 millimetres of glass wool where there is suspended ceiling

A1: Yeah

EC: And then 30 millimetres of EPS

A1: That is () 0.035, isn't it?

EC: It might be that it can go down to 0.035 () I have considered 0.038

A1: Okay () we just say that then

Their conversation ends as a fourth designer enters the room and the conversation turns to another topic. As the interaction above illustrates, the energy consultant provides the architect and the construction architect with information about insulation for floor heating. The architect writes down the information to keep it. The energy consultant is mostly absent from the renovation project, and the architect might need the information for subsequent work, so she writes it down on the paper. By now, the design of the floor construction seems to fit the instruction by the Danish Building Research Institute and, perhaps with a few corrections; the design can be adjusted to the specifications for insulation provided by the energy consultant. However, later in the project at a meeting on 20 May 2016, the architect presents the other designers with an issue.

Figure 6.26: The picture shows how the architect points at a printed section drawing.

A1: ((The section drawing)) is made rather quick () it is for the new building () it is to get in what we can () and what we found out was about the build-up of the floor construction () that we have very little room actually () down here *((points at the floor constructions))* on the floors () that we have some windows which actually go *((points, see figure 6.27))* all the way up underneath the slab construction () so, I had made some beautiful large standard constructions which could not at all be there () so () it is something like () there should be some very large sound-proofing membranes in here *((points, see figure 6.27))* () so, that we do not have any sound which can-

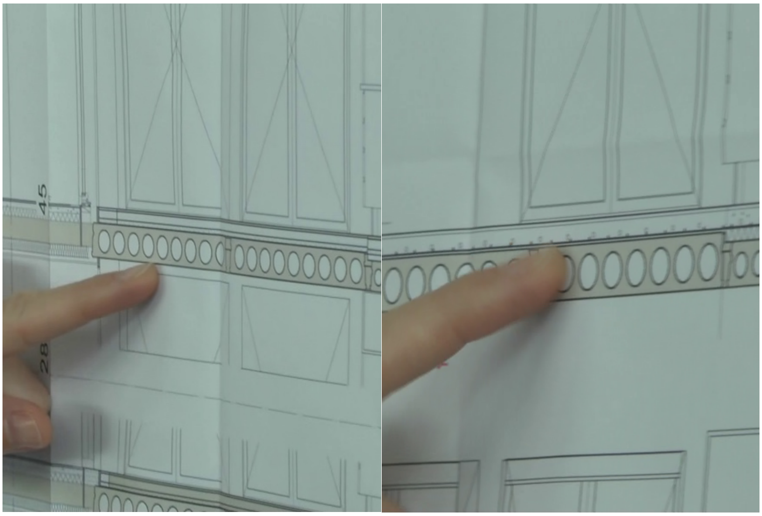

Figure 6.27: The left picture shows how the architect points at the top of the windows. The right picture shows how the architect points at a thin layer in the floor construction that represents the sound-proofing membrane.

CEN: Are there any changes to the build-up of that floor?

A1: That there is () because there is just no room to neither yours or mine constructions () that there is just no room for

The interaction illustrated above shows how the architect presents changes to the design of floor constructions. A construction engineer reacts somewhat surprised to the statement because he has considered the floor construction to be 'fixed.' The architect and the construction engineer have previously in the design process discussed the floor constructions and how they could be designed. Up until now, the construction engineer has regarded the floor constructions to remain as they had previously agreed. Nevertheless, the architect re-open the design of the floor constructions and state that the previous design does not work anymore.

CEN: What has been changed then?

A1: There are some window heights () I cannot get those floor constructions in

CA1: Where do the window heights come from?

A1: It is those 2400 ((millimetres in height))

CEE: Yeah, because it does not seem like that there is any sound-proofing membrane here *((points, see figure 6.28))*, right?

A1: No () and that there should be () there should be some very () there should be some sound-proofing membranes which are about 10 millimetres

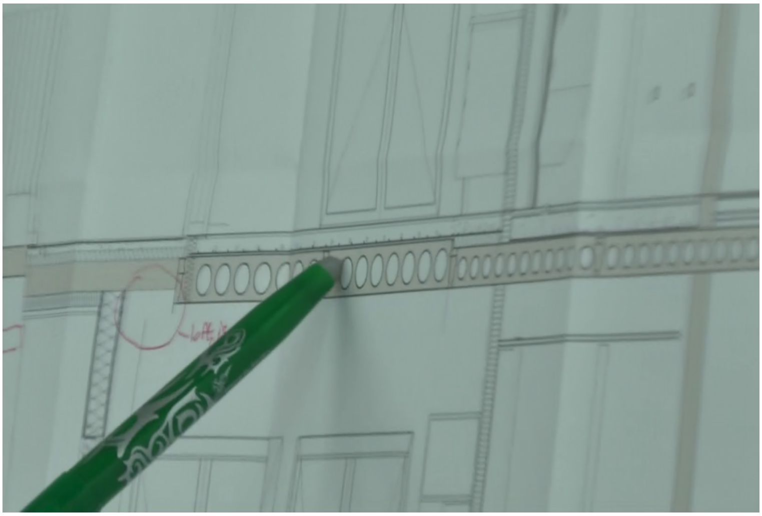

Figure 6.28: The picture shows how the construction engineer points at the floor construction with his pen.

CEN: Have you talked with (name of an architect from the architectural company)[8] about it?

A1: Yeah () he is making quality assurance on it right now

CEN: But those sound-proofing membranes, they cost a fortune ((in Danish: the tip of a jet fighter)). Do you know that? They do that

A2: Now () it is not so expensive () the tip *((everybody laughs))*

CEE: It depends on how many you should have *((giggles))* () and here we should have many

CEN: I only know one manufacturer of them () (the name of the manufacturer)

A2: But we cannot () what should we do?

CEN: No, no

From her work on the section drawing drawn in 1:20, the architect knows that the pre-agreed-upon floor constructions cannot fit when the building has a specific height, each storey has a specific height, and the windows should have a specific height. The first two relates to the existing building of which the new building is an extension. If the new building and the existing building shall have the same architectural expression, then

[8] The architectural company has to approve any significant design decisions taken by the designers at the engineering consultancy company since the engineering consultancy company is a sub-consultant to the architectural company in delivering the design of the energy renovation project.

they also should have the same height. The architect has found the height of the windows at 2.4 meters in the descriptions of the conceptual design given by the architectural company which has designed the energy renovation project. These constraints cannot be opened up by the designers and questioned. They will remain fixed unless the designers can get approval from the architectural company.

> CA2: It is because it has to be 24 high? () That is the intent ((of the architectural design))?
> A1: That is the intent, yeah () and then, either we make the windows lower *((points, see figure 6.29))* () smaller () or else then we have to settle for the room we have to the floor build-up () and then get what we can out of it

Figure 6.29: The picture shows how the architect points at the windows in the drawing.

> CEE: It is rather late now to begin changing the geometry and begin to make the windows smaller and so on () so, can it be solved with a membrane, then we do that
> A2: That we should not start to change now *((confirming))*
> CEE: It is too late, right?
> A1: Yeah

The architect suggests to reduce the height of the windows to make room for higher floor constructions, but a construction engineer and an architect react to this suggestion. They argue that the windows should remain as they are. They know, if the windows are changed, then the concrete constructions change, then the design of the concrete constructions need to be made anew, as well as the calculations for statics have to make again. The efforts in changing all these things are too high. They, therefore, do not want to change the window sizes.

The two situations described in this section illustrate how the work of the designers sometimes leads to unexpected situations. The architect and the construction engineer did not anticipate the changes in floor constructions. Nevertheless, design constraints from the architectural design require the designers to 'unfreeze' (Whyte et al., 2007) the floor constructions and design them anew. In this way, the situations show how designers sometimes open up design features which has until now been regarded as 'closed.' The architect's movement between detail drawings and section drawings provide her with knowledge about the issue regarding heights of floor constructions. Without both the work on detail drawings and the work on section drawings, the architect might not have 'seen' the issue. At this time in the project, the designers have become aware of the problem, and the next step for them is to figure out how to deal with the issue.

COMPETING CONCERNS

This section shows how the discovery of the issue with floor constructions develops into a dispute between two designers regarding how to approach the issue. The issue develops into a tension between 'the technical' and 'the spatial.' The section presents two situations in which a construction engineer and an architect discuss the issue. The first situation occurs later in the same meeting as described in the previous section.

> CEN: And about that I want to hear () we had talked about that in 'penthouse' there should be floor heating () now, I saw the floor construction over there *((points, see figure 6.30))* which is drawn in your model in the same thickness as all the rest () what did it result in () all that floor heating?

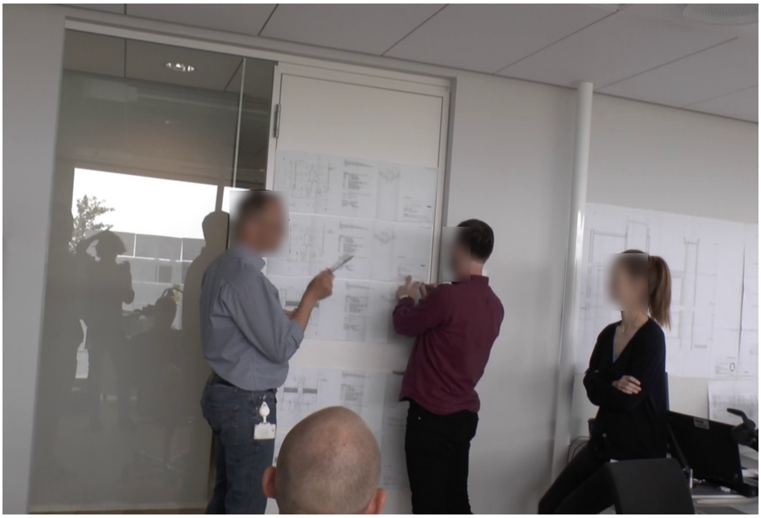

Figure 6.30: The picture shows how the construction engineer (to the left) points in the direction of a section drawing that hangs on a wall to the right of the picture.

A1: There is floor heating in 'penthouse'

CEN: But, how? () And what thickness?

A1: Well, the finish floor level is what I relate to () so, there is some insulation that has been removed

CEN: But it depends on how much () have you decided how much room it takes up *((shows his hands, see figure 6.31))* that floor heating? () Insulation? () What has been decided?

Figure 6.31: The left picture shows how the construction engineer makes a distance between his hands to indicate the height of the floors. The right picture shows how the construction engineer points at the drawing.

HPE: Up there () that is, what I have heard until now () it is decided to be wooden boards with grooves

A1: No () not in new build () it is a floating-

HPE: 'Penthouse', right?

CEN: New build part () in 'extension' *((points, see figure 6.31))*

HPE: 'Penthouse' in 'extension' is that what you talk about?

CEN & A1: Yeah

HPE: That is concrete

A1: It is a concrete layer with heating distribution tubes in it

CEN: With regular heating tubes?

A1 & HPE: Yeah

The interaction above shows how the construction engineer searches for an answer to how the architect has designed floor constructions with floor heating. The construction engineer wants to know how much space the architect has given to each material layer in the floors. After the designers have established what kind of flooring they are talking about, the construction engineer continues his request.

CEN: But then there is a floor build-up there at around 180 millimetres or something like that
A1: No
CEN: Yes
A1: No () there is just no
CEN: What is there then? () There is 75 millimetres of insulation and then 90 concrete, right?
A1: Well () there is not enough room for that () if the structural slab levels must be where they have been all the time () then I have almost no room
CEN: Then we cannot get floor heating
A1: That we can () but, really
CEN: Floor heating must have 75 millimetres of insulation if it should comply with the building regulations
A1: That I do not know
A2: We will look at it () later

The interaction shows how the architect and the construction engineer disagree about specifications for the floor constructions. The construction engineer draws on technical knowledge relating to how concrete floors with floor heating 'usually' are designed. This involves 75 millimetres of insulation and a concrete layer of 90 millimetres. The architect, on the other hand, draws on her spatial knowledge she has gained from working with the detail drawings and section drawings. Her work shows how the height of the floor constructions have to be low, and therefore, there is no room for the material layers which the construction engineer proposes. A construction architect suggests changing a design feature which has been deemed 'locked' by the designers. Namely, the levels of the hollow core slabs in the floor constructions.

CA2: But the structural slab level? () that?
CEN: That can also just be lowered
CA2: That can also just be lowered, yeah () in that way, it is not fixed
A1: You are in a warm house
CEN: Yeah () but you may not have floor heating () you must have 75 millimetres under the floor heating
CA3: Or else it warms downwards
CEN: Or else it warms downwards
A1: That is right
CA2: If we lower it all
A1: Yeah, then the structural slab levels must be changed

CA2: And that we must inform about in correspondence with our floor built-up
CEN: We have to get that one fixed () the floor build-up in 'penthouse' in 'extension', right? () And if it has to be hydronic, then it must be 90 millimetres in the concrete slab which the tubes should lay in, right?
HPE: Yes, you should have something underneath, right () you must have 40 millimetres over-
CEN: It takes up 90 plus insulation of 75 () that is 165 at least () then there is a few tolerances, then it is 170
CA3: And then a little bit of screed on top
CEN: Yeah, it ends up in 180 in total
A1: Yeah, it is some very thick floors () that have been drawn () it has then been edited () 'anyways', does not matter () I do it again

The architect displays frustration over changing the floor constructions, since, as she states, the floor constructions have been designed as the construction engineer proposes, then changed to fit new requirements, and now they have to be changed back to the original version again. The interaction shows how the tension between the architect and the construction engineer emerge based on their different approaches to the floor constructions. The construction engineer relates the floor constructions to building regulations and professional rules of thumb by stating the different material layers 'needed' for the floor heating constructions. The architect relates the floor constructions to what has deemed possible in her work with the section drawings. In this way, a tension emerges between a technical approach advocated by the engineer and a spatial approach advocated by the architect. At a meeting five days later, 25 May 2016, the two designers reopen the discussion about the floor constructions.

CEN: I think it could be nice () I think we are talking from () it would be nice if you draw the bathroom construction completely through
A1: But it is drawn
CEN: With levels on the floor and what there has to be, because there is *((indicate thickness with fingers, see figure 6.32))* a 180 millimetres' floor () so, there is an extra layer there () it is 75 in total () there must be () and there I have *((looks down on his papers, see figure 6.32))* drawn in those sections from long time ago that there is such a build-up which took up () I almost cannot remember what it was

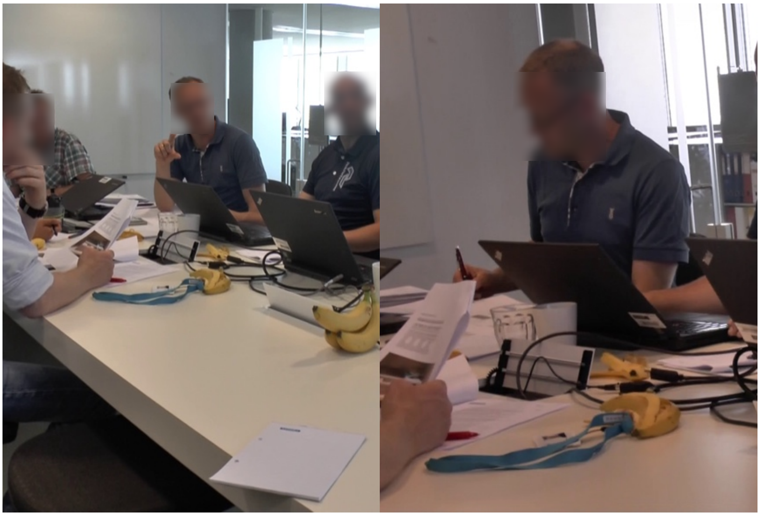

Figure 6.32: The left picture shows how the construction engineer makes a distance between his fingers to indicate the height of the floors. The right picture shows how the construction engineer looks into his drawings.

A1: No () but those I have also looked at, (name of CEN) () but your suggestion is also that there are 75 millimetres underneath those slab constructions
CEN: There must be 75 in total from floor heating and downwards to the next apartment
A1: Yeah () and then I go and talk with (name of VE) and we look at what it would mean for those installations which need to be placed there () underneath that slab construction () that means that he should have 250 millimetres of room underneath the 75 millimetres of insulation
CEN: But what I say, (name of A1), is that you should sketch that section accurately, so we can look at it, right? () Because those 75 is the insulation, there must be from the floor heating and down () that is underneath the floor heating in total
A1: I understand
CEN: That is, if you can place 50 millimetres on the top of the slab construction, then it is only 25 there must be underneath
A1: Yes, it is () I am trying to figure out with (name of EC) whether we can do it in such a way that we do not have anything underneath the slab construction () and he knows more about insulation and its properties
A2: If he vouches for this solution can we not just keep it? Because then it is what will be drawn

After finding out the issue regarding the height of the floor constructions, the architect works on possible solutions where there is space for insulation, concrete flooring, hollow core slabs, and more. She tries to move the insulation underneath the hollow core slab to minimise the height of the flooring above the hollow core slab. This suggestion results in a clash between the insulation and installations which run underneath the hollow core slab. The installations, in this case, are ventilation ducts and drainage pipes. The construction engineer suggests splitting the insulation in two parts by placing one layer above and one layer underneath the hollow core slab. The next sequence of interaction shows how another construction engineer returns to a question he had asked earlier in the meeting.

CEE: Okay () but just to return to my question () will you send me the detail you have made?

A1: Yeah () of course

CEE: Or will that also be changed if the construction frames also are going to be changed? () No () that slab is fixed in the level, right? () So, there I can get informed about the level on that?

A1: On the winter garden slab, right?

Figure 6.33: The left picture shows how the construction engineer walks over and picks up a picture of an insulation product. The right picture shows how the construction engineer stands and looks at the picture.

The paper which the first construction engineer picks up and takes with him over to his seat is a picture of a product model illustrating an insulation product from a manufacturer. The picture is sent by the energy consultant to the architect as a suggestion for insulation which is thin and might enable the designers to compress the floor constructions. The architect has brought the picture with her to the meeting to propose it as a possibility to reach a design of the floors. After looking at the picture, the construction engineer continues their talk.

> CEN: Well () the only thing I am interested in () basically () is the structural slab level () and that is entirely independent of what you choose to do with that insulation
> A1: Should we say that you get those structural construction levels today?
> CEN: Yeah () because whether it comes on top, or underneath, or choosing to have a better one on top and spare the one underneath, that does not matter () as long as the slab is fixed
> A1: The slab construction cannot be moved from the first floor to the third floor because there is not any room

The two situations show how two designers disagree about how to deal with the issue regarding floor constructions. The construction engineer suggests approaching it be drawing all the technical requirement for the material layers in the construction. In this way, he suggests, the designers can see and discuss the specificities of the floor constructions. He also underlines the technical requirements for the height of concrete floors with floor heating. The architect, on the other hand, relates to the spatial requirements she discovered from the section drawing and tries to solve the design by squeezing all the required materials into the construction. In her attempt to solve the issue, she tries to place insulation different places and discover even more constraints from the installations in the floor construction. The two approaches oppose each other because they relate either to the 'technical' or the 'spatial.'

The architect strives to solve the issue she has discovered, and in the process, she has to 'align many allies' (Latour, 1987). The architect has to make sure that the construction engineer is satisfied concerning the design of the hollow core slabs. The ventilation engineer has to agree that the floor constructions do not intervene with the ventilation ducts. The plumbing engineer has to approve that the floor constructions do not interfere with the drainage pipes. Moreover, the floor constructions have to be as thin as possible to fit the constraints from the architectural design. All of these relations to designers, drawings, descriptions, and requirements have to come together, and their interests are aligned.

UNFIXING & RE-FIXING FLOOR CONSTRUCTIONS

This section shows how designers' engagement with material objects contributes to the discovery of unexpected design features or unanticipated design issues. The architect moves from detail drawings to section drawings, and both types of drawings allow her to see and understand design features in different ways. Her work with the detail drawings only attends to the material layers of the constructions separated from the rest of the building design. Her work with the section drawing, on the other hand, allows her to relate different constructions to each other and realise the spatial constraints of the architectural design. The architect's engagement with drawings is important in her ability to know and understand design features. Moving between drawings, and in this way, moving between scales, she relates different requirements and discovers the issue. The empirical examples show how the knowledge of the designers is tied to their engagement with material objects. Designers' interaction with material objects allow them to see aspects of the building design in different ways, and as they move from one drawing to another, the designers continuously develop their understanding of the design.

This section also shows how attempts to solve issues late in the design process might be painful because many aspects of the building design gradually become 'locked' or 'fixed' in the project. In the empirical example, the hollow core slab, the ventilation ducts, and the drainage pipes are regarded as 'fixed' by the designers, and the architect is not able to suggest changes to those design features. As more and more design features get fixed, the designers struggle to solve pressing design issues. Even though the construction engineer suggests to fulfil the technical requirements for floor heating, the actions of the architect are limited because of the many design features which cannot be changed. She asks the energy consultant to suggest insulation material which is as thin as possible to achieve the insulation requirements. Furthermore, she struggles to get the insulation placed in the floor constructions. Material objects stabilise design features, but as more and more design features get stable, the designers struggle to change the states of the building design and solve pressing issues.

The next section summaries the analytical points for Chapter 6.

KNOWING & ACTING WITH OBJECTS

This chapter shows how influential objects are in making energy renovations knowable and actionable. Drawings and sketches partially materialise design features and partially hide other design features. In this way, drawings and sketches illustrate the current design features that the designers have agreed upon, and simultaneously, the drawings and sketches indicate areas of the design that are yet to be explored, eliciting further design work. The chapter shows how the designers bring energy-saving design features 'into existence' by making material objects and also moments where the designers hesitate to materialise design features because of a lack of agreement. Knowing and acting on energy-saving design features, such as the specification for insulation, involve engagement with material objects such as drawings and sketches. Engagement with material objects allows the designers to translate general energy requirements into specifications in detail drawings, section drawings, and documents. This chapter illustrates the recursive processes and pressure that designers experience when trying to solve specific problems concerning energy-saving design features.

In the example concerning a thermal bridge, the designers learn about the energy consultant's intentions regarding thermal bridges through the use of sketches. The energy consultant presents the designers with a sketch indicating his intentions, and in another moment, the designers discuss another sketch that also illustrates his intentions. However, as stated by Latour (1986), displacement is not enough if you do not have mobilisation. In other words, the displacement of the energy consultant's intentions into sketches do not mean that the designers are mobilised and follow his intentions. The designers face competing concerns for the same joint between building components as well as a time pressure that makes them go against the intentions of the energy consultant. The designers betray the will of the energy consultant. Furthermore, the energy consultant learns about the betrayal through engagements with emails and drawings and convinces the designers to change the drawings following his intentions. The example shows how the designers make repeated interactions with drawings to understand the problems relating to the joint between building components as well as to solve the problems they find during the process.

In the example concerning basement insulation, the designers hesitate to materialise basement insulation because they disagree about the specifications. When the designers agree about the specifications, they begin to sketch and draw the insulation. A condition for the materialisation of design features is agreement among the designers, but material objects are also used by the designers to negotiate design features, and in this way, reach an agreement. In the example, one particular material object, an email from the energy consultant, plays a crucial role in creating an agreement by clearing away any doubt from an architect. The example concerning basement insulation illustrates how the designers stabilise design features by materialising them in drawings, sketches and emails. The example also shows how the designers hesitate and become uncertain when they are without material objects that indicate specifications about basement insulation. Material object both allow the designers to stabilise and fix design features when they reach an agreement, but material objects also allow the designers to open up design features for negotiation and put these features under scrutiny.

The example concerning insulation for floor heating illustrates how drawings temporarily stabilise or 'fix' design features that later in the design process may be subject to re-design. Similar to the previous example, the example of floor heating insulation shows how material objects freeze already-agreed-upon design features. However, stabilisation may only be temporary. In this example, the designers 'unfreeze' the design of floor constructions because an architect finds out from working with section drawings that the current designs do not fit constraints from the architectural design intentions. The insights of the architect open up the design of the floor constructions for negotiations around specifications for different material layers, such as thermal insulation. The example shows how the designers' engagement with material objects is crucial in both learnings about unexpected design issues and attempts made to solve such issues.

This chapter shows how the designers engage with material objects in different ways to make energy-saving design features knowable and actionable. The designers treat some material objects, or parts of the material objects, as 'given,' that is, as reference points, informative tools, or as stabilised design features. The designers consider these material objects as 'fixed' and strive to 'fix' as many design features as possible before their deadline for delivering the project. The designers treat other material objects, or parts of material objects, as open for interpretation and interrogation in a continuous exploration of design problems and solutions. Many of the material objects are inscriptions that produce incomplete representations of the building and the building components. Designers try out their ideas through the materialisation of specific design features that lead to further explorations. Sometimes the designers resolve disagreements through these iterations. At other times, the designers resolve disagreements through power plays as when the energy consultant enforces his interests in the project design. Iterations coupled with time pressure lead to compromises, accommodation of different concerns, and (gradually) stabilisation of decisions.

CHAPTER 7 Discussion

Discussion

THE ‘EVERYDAYNESS’ OF DESIGNING ENERGY RENOVATIONS

Chapter 5 and 6 illustrate the practical making of an energy renovation as designers translate and transform initial intentions about minimum energy performance into detailed and specific design solutions. As Guy & Shove (2000) describes it, the practical work is challenging as designers reverse and re-interpret generic knowledge about energy reductions into localised, context-specific design problems (p. 53). In working with documents and drawings, the designers develop their ideas on how to renovate the building. In the course of the design process, the designers move from the abstract (ambitious client demands regarding minimum energy use) to the concrete, specific suggestions as to how to change the existing buildings in order to minimise energy use. It is through the designers’ everyday design practices that their design task (renovating the building) becomes knowable and, hence, actionable. They enable the designers to develop “realisable courses of action” (Comi & Whyte, 2017). It is through the ‘everydayness’ of designing energy renovations that designers produce the detailed design of the projects and tackle the challenges and conflicts that design processes entail.

Focus on everyday practices of designing energy renovations is vital since researchers and practitioners risk overlooking the challenges designers face when they translate abstract energy-saving goals into concrete project material if mundane design practices are not considered. The challenges and conflicts that designers experience through their design processes affect the renovation outcome, and if researchers and practitioners do not consider these challenges, then intentions of reducing energy consumption are likely to fall short. Design processes condition the ‘making’ of energy renovations, similar to how the subsequent construction processes and the occupancy of the buildings also condition the ‘making’ of the energy renovation and the consumption of energy in the buildings. In short, without understanding design practice, recommendations for energy-efficient building designs are likely to overlook the challenges that designers meet in their everyday work. Furthermore, neglecting everyday practices of designers also abandon the changes to both the design and the energy-saving goals that happen throughout energy renovation processes (Palm & Reindl, 2018).

The everyday design practices studied in this thesis involve the discovery of unexpected issues that create detours and moments of doubt that prolongs specification of design features. In the example concerning floor constructions with floor heating, the designers became aware of an unexpected issue through their work with drawings. Even though the floor constructions had been designed and drawn, the designers' drawing practices made them realise limitations in space for the floor constructions. This study also shows how the everyday practices of the designers involve moments of doubt as for when the designers hesitated to draw basement insulation on the drawings because they were unsure about the energy consultant's specifications. Uncertainty about energy performance specifications does not only pertain to design activities concerning energy models as shown by Eidenskog (2017). Similar to Eidenskog, this study illustrates certainty as achieved and not as given a priori (*ibid.*, p. 226). The designers in this study achieve certainty through their material design practices. Both the discovery of an unexpected issue and the moments of doubt illustrate how designing energy renovations involves turn of events, setbacks, unexpected circumstances and detours as the designers continuously explore the building design. The outcome of energy renovations is as much affected by the events happening in the course of the design process, such as the discussions, negotiations and agreements presented by Palm & Reindl (2016), as energy renovations are affected by the energy-saving strategies designers and building clients decide to take in the course of projects.

In focusing on the 'everydayness' of designing energy renovation projects, this thesis attends to the 'nitty-gritty work' of the designers while they produce energy-saving design features. Attending to the nitty-gritty work, this study illustrates how the designers constantly involve themselves in tensions between three considerations. The first consideration deals with the existing buildings and provides the conditions with which the designers have to work (or work around). As the designers work on immediate and pressing issues, they explore and become more aware of the existing buildings and how the existing buildings affect their design suggestions. For example, as seen in the example concerning floor heating, the existing buildings determined the floor-to-floor height in the extension of one of the buildings that affected the proposed design of floor constructions. As illustrated by Yaneva (2008), buildings are in this way able to 'surprise' the designers and create changes to current designs. Another consideration that the designers involve themselves with is the project constraints that set limits for the designers' work. Project constraints involve agreed deliveries (time), project budget (cost), and project specifications (quality). This consideration is one that project management literature concentrates on (Kurokawa et al., 2017, p. 912). The most prevalent of these constraints in this study is the consideration of time since the designers came under time pressure towards the end of the design process, making the design negotiations tense. The third consideration that the designers involve themselves with is the constant discovery and redefinition of performance requirements and specifications for building components and installations. It is well-known from the design literature that designers have a 'reflective conversation with the materials of the situation' where unintended changes and discoveries arise (Schön, 1983, p. 132). In the same manner, the designers continuously discover new relations as they work on drawings and documents. In the examples concerning a thermal bridge and the floor heating systems, the designers struggle to fit all the required building materials into the small spaces of building joints and floor constructions. While the designers attempt to make all the things fit, they are ready to change the specifications of some building materials to make other building materials fit. All of the three considerations affect each other and designers strive to solve the issues that appear when one consideration affects the others.

The making of energy renovations involve the practical, mundane and everyday practices of designers, and this study illustrates how such design practices involve persuasive and learning processes. Multiple design strategies to improve the energy performance of existing buildings exist (Guy, 2011, p. 140; Guy & Shove, 2000, p. 67), and since designers consider different strategies to be the 'best' or most 'efficient' strategy, designers attempt to persuade others to follow their design suggestions. As this study shows, processes of persuasion can both be successful, as when the energy consultant redefine the energy requirements, or be unsuccessful, as when the ventilation engineer fails to convince the estate board members to install centralised ventilation. The design of energy renovations also involves learning processes, in the sense that the designers continuously discover new aspects or unforeseen relations between building components. In both processes of learning and persuasion, interactions between designers and material objects constitute the processes. When designers attempt to persuade others, material objects play a vital role in stabilising and moving statements without distortion. Furthermore, in the learning processes, designers 'fix' and 'unfix' design features through engagements with material objects.

The following three sections discuss the processes of persuasion, learning, and how material objects fix and unfix design features.

PROCESSES OF PERSUASION

The design of energy renovations, like many other construction projects, depends on the collaboration between designers for the delivery of a detailed project design. Designers with different professional training, in this case, architects, engineers with different specialities and construction architects, collaborate to produce a set of descriptions and drawings that represent the energy renovation project which is going to be built. In such collaboration, many interests and many opinions about how the design should be made exist. However, as this study illustrates, sometimes interests collide, and negotiation of interests occurs. For instance, when the ventilation engineer disagreed with the client's manager about which ventilation concept would be best for the housing estate. The two designers mustered allies as attempts to convince the other part in 'processes of persuasion.' Through the mobilisation of allies and translation of interests, the designers attempt to convince others to follow their suggestions. In this way, the designers mobilise a range of different 'tricks' as attempts to convince others.

All of the five examples presented in chapter 5 and 6 show moments where the designers try to convince others to follow a suggestion. From the ventilation engineer that attempts to convince the estate board members to install centralised ventilation to the construction engineer and the architect in the example with the floor heating that try to convince each other about what the issue and possible solutions are. Based on these observations, this study highlights that processes of persuasion are crucial for designers to make energy-saving design features knowable and actionable since the act of persuasion enhances interests in energy savings through the design processes. However, as the example with the thermal bridge illustrated, if energy-saving interests are not cared for through the design process, then the designers might try to avoid energy-saving specifications in order to solve pressing issues and intentions of energy savings are likely to fall short.

Processes of persuasion and negotiation of interests do not figure prominently in the existing literature on energy renovations. Except for Palm & Reindl (2018) who argue that barriers to improving energy savings through the design of energy renovations exist in a specific social context in which actors negotiate what measures to adopt and what measures to reject (p. 63). However, Palm & Reindl only touch upon the negotiations. This study suggests that negotiations of interests and attempts of persuasion permeate the design processes involved in energy renovations. Designers do not only decide whether or not to have energy-saving measures, but energy-saving measures compete with many other design concerns where trials of strength are likely to happen. As Zapata-Lancaster (2014) argues, designers need to balance energy targets with many other building design aspects which makes the design for energy savings difficult (p. 145). Because energy-saving measures compete with many other concerns, processes of persuasion can help the designers keep their interests on energy-saving design suggestions rather than avoiding energy-saving measures, as shown in the thermal bridge example.

Although most of the energy renovation literature overlooks negotiation of interests, studies within the building design literature highlight the importance of negotiations and trails of strength. For example, Kurokawa, Schweber & Hughes (2017) focuses on negotiations around particular design issues and how processes of persuasion reformulate stakeholder interests, even if the concerned stakeholders are absent from the design process (p. 922). Furthermore, Tryggestad, Georg & Hernes (2010) argue that project goals and design ambitions are not only the product of social negotiations, but goals and ambitions are effects of socio-material trials of strength (p. 703). This study takes the same analytical stance as Kurokawa et al. (2017) and Tryggestad et al. (2010) and suggests that negotiations of interests, socio-material trail of strength, and processes of persuasion are all part of the everyday practices of designers in making energy renovations knowable and actionable. According to Ewenstein & Whyte (2009), the conceptual design of buildings involves technical, social and aesthetic forms of knowledge that designers need to develop and align (p. 7). This study suggests that alignment of interests (or different kinds of knowing the building design) is based on processes of persuasion and how designers agree to design the building in particular ways.

Chapter 5 and 6 illustrate how the designers attempt to persuade each other with the means of material objects. In the example with the energy requirements, the energy consultant writes a document that presents his suggestion for a new definition of the requirements as an obligatory passage point. In this way, the energy consultant uses the document as an interessement device by illustrating that interests in passive houses, energy classes and the building code are all satisfied by following his suggestion. In the example with the thermal bridge, an architect uses a printed sketch to persuade the others to reduce the insulation thickness in a building joint. Both examples show how the designers translate their interests into material objects and use the objects as attempts to convince others. Based on these observations, this study suggests that attempts of persuasion rely on both material and social relations. Taking the argument further, this study suggests that material objects scaffold processes of persuasion, in the sense that objects provide stability in the course of negotiations of interests. Material objects allow the designers to stabilise or 'freeze' (Whyte et al., 2007) statements across time and space and in this way present arguments to others even if these other designers are not present in the particular situation. Material objects, such as drawings, contribute to ongoing negotiations of interests and can be used for political purposes (Bendixen & Koch, 2007), like when the ventilation engineer and client's manager mobilises objects that support each of their interests.

Processes of persuasion are one of the challenges that designers face in their everyday practices of designing energy renovations. If research and practitioners overlook attempts made by designers to convince each other, then ambitions of energy savings risk losing the attention of the designers to the many other design concerns involved in energy renovations. Processes of persuasion play a vital part in the way that designers make energy-saving design features knowable and actionable.

Processes of persuasion are one challenge that designers face during the design of energy renovations. The next section discusses another challenge, namely the learning processes that the designers experience.

PROCESSES OF LEARNING

Chapter 5 and 6 show how the designers work with material objects and negotiate with each other to make energy-saving design features knowable and actionable. The designers explore the building design through engagements with material objects and by presenting issues and design suggestions to each other. Through their work on specific drawings and documents, the designers realise relations between design concerns and can act on these insights. The designers engage in processes of learning where they discover, reveal, explore design features and issues, and try out different possible solutions. The designers' learning processes are crucial in making specific design features related to energy-saving measures known. In the example with the floor heating systems, the architect discovered a design issue related to the height of the floor constructions. This issue later developed into a concern for the location of the thermal insulation for the floor heating system. It is through the architect's work with detail drawings and section drawings that she learned about the issue and told the other designers about the issue. When the designers stumble upon design issues, as the architect did, they involve themselves in the same learning processes to try out different options and possible solutions. In the same example, the architect discussed the issue with the ventilation engineer, the energy consultant, and the construction engineer and tried to solve the issue. As possible solutions, the architect tried to place the insulation on top of the hollow core slabs, underneath them and divided it into two parts. All these efforts are part of the designers learning processes. To explore specifications, discover various relations, and try out different options.

From the perspective of learning processes, the design of energy renovations resembles many other design processes, in the sense that most design processes involve the discovery of design features and testing of design possibilities. According to design scholars, most designers work with 'ill-defined, ill-structured, and wicked problems' that do not lend themselves to straightforward problem-solving (Cross, 1982, p. 224). In this study, the energy-saving design features are ill-defined and the designers work to specify them as they develop their knowledge about the building design. The designers do not know the energy-saving specifications before the design process, and it is only through their design practices that the specifications are made knowable and actionable. Designing energy renovations also pertain to the ill-structured and wickedness of design problems because the designers have to work out the numerous interrelations and effects that energy performance has with the many other design concerns. In all of the five examples, issues relating to energy performance relates to other design concerns (such as stability or architecture), project constraints (such as schedule or budget), and the existing buildings (such as the existing building materials). Based on the issues that the designers discover, the designers work on both specifying the problem and the solution simultaneously. According to design scholars, most designers do not work from a fixed definition of a problem to one specific solution; instead, designers develop and refine both the formulation of the problem and ideas for solutions in constant iterations (Dorst & Cross, 2001, p. 434). The discovery of energy-saving design features relies on the iterative process of defining both the problem as experienced by the designers and the many possible solutions that might solve the problem. In the example with the floor heating system, the architect gradually developed both several problems to the location of insulation, but she also tried out different strategies to solve the problems she found.

In the course of design processes, learning is crucial since designers continuously explore and discover new aspects or relations that are worth considering and that may have an impact on other, already known, design aspects. In this way, designers engage in a "process of discovery, of learning, and even a form of research" (Lawson, Bassanino, Phiri, & Worthington, 2003, p. 327). Designers gradually develop their knowledge about the design problem and possible solutions, and they propose, experiment, and learn from the results until they reach a satisfactory result (Lawson & Dorst, 2009, p. 34). In this study, the designers continuously discover new insights and experiment with different design suggestions through their engagement with material objects and their negotiations to define design features. Work on drawings reveal specific issues, as the example with the floor constructions, and emails provide necessary information for closure, as the example with the basement insulation. The designers' engagement with material objects is important since the material objects enable them to see particular things and relate design aspects in different ways. Design scholars highlight this as by referring to how designers involve themselves in a 'reflexive practice' with the 'materials of the situation' to deal with the complexity, uncertainty, instability, uniqueness, and value conflicts that pertain most design processes (Schön, 1983). The designers' learning processes also rely on their interactions during negotiations where material objects play a vital role by visualising and stabilising certain design features.

This thesis emphasises on processes of learning because such processes are vital to understanding how the design of energy renovations are made knowable and actionable by designers and material objects. Appreciating processes of learning breaks with the prevalent attitude within most of the techno-economic literature on energy renovations where scholars suggest that 'energy-efficient' measures exist 'on the market' and it is only a matter of implementing them in energy renovation projects. This study suggests that all energy renovation projects are unique and energy-saving measures that need to be modified and translated into the local circumstances of the specific project.

Translation of energy-saving measures rely on the practices of testing design solutions, exploring relations between different design aspects, and perhaps discovering new relations or unexpected issues. Processes of learning highlight the efforts that designers have to make to translate general energy-saving measures into specific design suggestions. In the example with the thermal bridge insulation, the designers have heard the general rule from the energy consultant of 'reducing the number of thermal bridges in the thermal envelope and possibly reduce the heat losses from them.' However, it is in the discovery of the details concerning specific joints between building components that the designers begin to realise what this requirement means. It is through the designers' daily work that they discover such issues, as the issue regarding the thermal bridge insulation.

Processes of learning seem to be overlooked in most of the existing literature on energy renovations. However, within the social-science-based literature on energy-efficient buildings, a few notable scholars highlight the importance of 'social learning' between installers and users (Glad, 2012), between designers, manufacturers and users (Rohracher, 2003; Rohracher & Ornetzeder, 2002), and between researchers and practitioners (Gluch et al., 2013). Furthermore, a study by Hojem, Sørensen & Lagesen (2014) draws attention to processes of translation and social learning with which a design team decides to expand the initial energy-saving ambitions and go beyond the requirements in the building code. These studies draw attention to the social learning involved in the design and use of energy-efficient buildings; however, these studies fail to notice the material practices through which energy-efficient buildings are made. This study emphasises that material objects are vital elements in the learning processes since material objects enable the designers to visualise and grasp, at least partially, the building design, making it knowable and actionable. For example, the project documents in the example where the energy consultant translate the energy requirements into a new set of requirements enable the energy consultant to understand, at least partially, the energy-saving ambitions in the project. That is, the energy consultant can learn about some of the previous statements made by the building client organisation about energy requirements. Not all of their discussions are included in the documents. In the example with the basement insulation, an architect learns about the intentions of the energy consultant through an email. Before she receives the email, she was not sure how the basements should be insulated, but the email provided this information to her. In other words, this study considers the learning processes that designers experience as social and material practices involving both negotiations and material objects.

The literature on building design processes highlights the role of material objects in learning processes. For example, Whyte, Ewenstein, Hales & Tidd (2007) observe how designers use material objects in processes of collective sense-making. In these processes, the designers pursue the definition of design problems and the exploration of solutions. Building design scholars argue that knowledge about the building design develops as designers engage with material objects and the concept of the building become defined and refined through such processes (Ewenstein & Whyte, 2009). Development of the designers' knowledge about design features happens through iterative, even dialogical, processes where designers and material objects act as agents (*ibid.*, p. 28). In the example with the floor heating system, the process of defining the insulation went through several iterations between situations where the designers met to discuss possible solutions and situations where the architect worked on different design suggestions. Both situations rely on a dialogue between designers and drawings. This example also shows how the interaction between designers and material objects may lead to unexpected insights. The architect discovered an issue relating to the floor constructions by working on both detail and section drawings. Tryggestad, Georg & Hernes (2010) observe a similar situation where the designers thought they knew the building design sufficiently, only to discover, through engagements with material objects, that their assumptions did not hold (p. 702). The interaction between designers and material objects is vital to test design solutions and explore building designs. Learning processes involve gaining knowledge about the building design, but, as Kurokawa, Schweber & Hughes (2017) argue, knowledge production, or learning processes, is not independent of the people and objects that produce the knowledge (p. 921). To gain insight into the learning processes involved in energy renovation projects, researchers need to include the interactions between designers, but also the interaction between designers and material objects.

Since both the persuasive processes and the learning processes rely on interactions between designers and material objects, the next section discusses the role of material objects.

PROCESSES OF FIXING & UNFIXING DESIGN FEATURES

The persuasive and learning processes described above involve interactions with material objects, but the way the designers engage with material objects illustrates 'processes of fixing and unfixing' design features. As the designers work with different design issues, they move between sets of stabilised, specified, 'fixed' design features and sets of unstable, unspecified, 'unfixed' design features. The fixed set of design features provide reference points for the designers and highlight the previous already-agreed-upon design decisions. The unstable set of design features is decisions and features which are not yet explored, not yet decided on, and remain open for negotiations. Material objects play a vital role in processes of fixing and unfixing design features since the materialisation of design aspects makes the designers consider them as 'locked' or 'still unspecified.' When designers fix design features into material objects, they stabilise these features, even if the stabilisation may only be temporary. Conversely, when designers unfix design features, they open them up for scrutiny and make them amenable for further work.

The existing literature on the design of energy renovations and energy-efficient buildings does not draw attention to the stabilisation and destabilisation of design features. Even though scholars who take a practice-theory approach to their studies highlight the social and material configuration involved in the design of energy renovations (e.g. Palm & Reindl, 2016, 2018) and the making of energy-efficient buildings (e.g. Guy & Moore, 2005; Guy & Shove, 2000), these studies do not shed light on how the materialisation processes occur. The literature on building design processes, and especially the studies that take an actor-network-theory approach, emphasises the role of material objects in stabilising designs and making designs fluid. If we want to understand how energy-saving measures become stabilised into building designs, then we need to study how designers engage with material objects and their practices of 'fixing' and 'unfixing' design features.

This study illustrates how the designers work on different concerns in parallel. For example, the designers try to solve the three issues relating to the thermal bridge, basement insulation and the floor heating in parallel at the end of the design process. In order to move from one issue to another, the designers establish some design features which they agree on by drawing, sketching, or writing them down. Returning later to the issue, the designers can see and re-visit what has previously been agreed and what has previously been explored to make the design features as they currently are. The gradual stabilisation of design features is vital for the designers in delivering the project, but also to explore relations between different design aspects. Furthermore, the destabilisation of design features is equally crucial since these moments make it possible for the designers to re-evaluate, re-make, and re-negotiate design features that previously had been taken for granted or they considered as 'fixed'. In the example with the floor heating, the designers destabilise the design of the floor constructions to re-negotiate and re-make the designs.

Scholars within building design processes emphasise on the stabilisation and destabilisation of design features through interactions between designers and material objects. However, they present it in different ways. For example: As matters of freezing and unfreezing design features where designers treat them as frozen or fluid (Whyte et al., 2007). As materials that continuously evolve and unfold design features or reference points that stabilise some aspects and the designers treat as given (Ewenstein & Whyte, 2009). As processes where design decisions either get fixed in material objects or remain open to ongoing negotiations, and where an increasingly larger 'overlay of devices' intensifies the durability of particular design features and render them non-negotiable (Kurokawa et al., 2017). Material objects enable designers to both stabilise and destabilise design features. This study shows how the document written by the energy consultant concerning energy requirements both destabilises the previous definitions of energy requirements and stabilises his definition in the project. Furthermore, even if the sketches illustrating insulation to prevent a thermal bridge were stabilised on paper, the design team negotiate this insulation and change it. Stabilisation depends on both inscription and mobilisation (Latour, 1986).

This study emphasises on the competing concerns, translation of interests, and trials of strength that happen during the design of energy renovation projects. All these processes make energy-saving ambitions stand their test and risk diminishing energy-saving design features in the course of the projects. Material objects enable designers in both stabilising and destabilising previously agreed-upon decisions and design features. However, such stabilisation and destabilisations happen within processes of negotiations which also can stabilise and destabilise design features. Research on the design of energy-efficient buildings and energy renovations overlook the processes of materialisation and negotiation in making energy-saving ambitions more or less durable in the course of projects. Researchers and practitioners that attempt to understand how energy-saving ambitions can get more prominence in the design of buildings should focus on processes of materialisation and negotiation since such processes shed light on how energy-saving measures become durable or unstable over time.

The next section discusses what it means to 'know about design' opposed to 'know through design' and sums up the main points from the chapter.

KNOWING ABOUT DESIGN & KNOWING THROUGH DESIGN

This thesis aims to shed light on how designers make energy renovations knowable and actionable. Through such effort, this thesis attempts to produce knowledge *about* design processes in which designers bring energy-saving measures into being. Other scholars within the literature on the design of energy renovations also provide knowledge about design processes (e.g. Mortensen et al., 2017; Nielsen et al., 2016). Compared to the existing literature on the design of energy renovations, this thesis provides an alternative view of design processes. However, all literature on the design of energy renovations provides different perspectives, attitudes and sensibilities in the pursuit of understanding the design processes better. Scholars within other research fields, such as design studies or the field of building design, also attempt to gain insights to how designers come to know their object of inquiry, how the materials of the situations determine certain possibilities and realisations, and how design processes in general develop. Such efforts are all attempts to shed light on the 'machinery of design' – that is, to understand how design is made. Such efforts can be termed as attempts to 'know about design.' Opposed to these efforts, this study illustrates how the designers make energy-saving design features knowable and actionable *through* design processes. The observed designers do not concern themselves with speculations about how researchers understand design processes. The designers are concerned about delivering the project on time. The designers work hard to understand the building design. They produce drawings, documents, sketches, notes, emails, go to meetings, work individually, present issues, try to solve issues, and so on. All of these efforts are made to 'know through design.' Energy-saving measures become knowable and actionable through the design practices of the designers. It is only practising design that designers can gain insights about the energy renovation project as they get. In this way, knowing about design is one thing, and knowing through design is another thing.

In an attempt to gain insights into the design of an energy renovation, this thesis illustrates how the designers make energy-saving design features knowable and actionable through their everyday design practices. Considering the 'everydayness' of designing energy renovations is crucial since it is through everyday practices that designers translate ambitions of low energy consumption into specific details and descriptions. In their everyday practices, designers experience challenges and conflicts that risk diminishing the energy-saving ambitions because other concerns pressure the designers. This study shows how the everyday practices involve discovery of unexpected issues, hesitation concerning specific design features, and struggles to specify energy-saving measures. As the designers work on the energy renovation project, they continuously involve themselves in tensions between information about the existing buildings, project constraints provided by the building client, and the continuously discovery and redefinition of performance specifications that originate from their design processes. Based on the everyday practices of the designers, this thesis emphasises on the persuasive and learning processes from which energy-saving design features originate.

Designers enter into processes of persuasion as they develop their knowledge about energy renovation projects. Because of the many interests that exist in construction projects, designers engage in translation of interests and trials of strength. The outcome of such translations and trials of strength can either benefit energy-saving ambitions or circumvent them. An increased understanding of persuasive processes is vital to enhance the strength of energy-saving measures, because if persuasive processes are overlooked, then ambitions of energy savings risk of becoming diminished. This study shows how material objects scaffold processes of persuasion, in the sense that objects provide stability in the course of negotiations of interests. The persuasive processes are only one type of challenge the designers face during the design of energy renovation projects.

Another challenge is the learning processes that the designers experience. A crucial part of the design processes is the exploring and discovering of design features through the project. This study shows examples where the designers discover unexpected issues relating to floor constructions and how they only specify basement insulation when they learn about the interest of the energy consultant. The designers engage in learning processes by interacting with material objects that let them consider partial design features and relate them to other design features. The designers not only try out possible solutions to the problems they find, but the learning processes also change the problems as the designers experience them. The designers develop both the issues at hand and the possible solutions to them – a vital aspect of the learning processes in the material practices of exploring and discovering the building design.

In both the persuasive processes and the learning processes, the designers engage with material objects to negotiate and discover design features. Through the design process, the designers also engage with material objects in a way that enables them to 'fix' certain design features and 'unfix' other design features. Sometimes, the materialisation of design features makes the designers consider them as 'locked' and therefore as unchangeable. In other situations, the materialisation process makes the designers question design features and enable them to open up design features that previously have been considered 'fixed.' In this way, material objects stabilise design features; however, only temporarily. The stabilisation of design features depends on both the materialisation of design features, but also on the negotiations happening around the material objects. Even if design features are materialised and considered ‘fixed,’ designers may reopen design features and once more negotiate the specifications. Based on these insights, it is crucial to study the interaction between designers and material objects to see how the stabilisation and destabilisation of design features happen in the course of projects.

The next chapter presents the conclusion by summarising the main points of this study.

Conclusion

THE EVERYDAY DESIGNING OF ENERGY RENOVATIONS

Energy renovations are crucial means to reduce energy consumption from the existing building stock. However, research does not widely attend to the practical details of designing for energy savings. Much research focuses on the technical and economic aspects of energy renovations. However, energy performance as a design problem remains overlooked or taken for granted in most of the existing literature. This study examines how professional designers translate ambitious energy-saving targets provided by the building client into detailed and concrete design specifications. By following the practical making of an ambitious energy renovation project, the analysis demonstrates how the designers make energy-saving design features knowable and actionable through negotiations and engagements with material objects. As the designers work on specifying the energy renovation project, the designers engage in persuasive and learning processes in order to make energy-saving design features known and actionable. The persuasive processes involve the enrolment of allies when the designers attempt to define design features and get other designers to follow their suggestions. The persuasive processes also involve the partial materialisation of design features as resources in struggles between different designers' interests. The learning processes involve engagements with material objects that enable designers to explain, learn about and negotiate design features through the design process. When the designers engage with material objects, they discover new insights, explore previously unknown relations between problems and solutions, and they can share and discuss solutions with each other. This thesis highlights the importance of studying the everyday practices of designers as they design energy renovations since if research does not draw attention to the everyday challenges and conflicts happening during the design of energy renovations, then ambitions concerning minimum energy consumption are likely to fall short.

Energy savings are often assumed to be well-known, well-defined, context-independent, and a matter of technique (Guy & Shove, 2000). However, this study documents that energy savings are not given and designers make energy-saving measures knowable and actionable through design practices. Furthermore, energy-saving specifications change throughout the design processes as an effect of the many translations and mediations of interest and trials of strength occurring in the processes. If researchers treat the design of energy-saving measures as 'black-boxed' entities (Latour, 1987), then scholars risk overlooking the possible changes energy-saving measures go through as they are translated from abstract energy requirements into specific design suggestions. As designers and material objects mediate interests in energy savings into the design processes, they simultaneously change and transform the energy-saving measures. Instead of discussing what practitioners 'should' or 'ought' to be doing, this research suggests focussing on how the design of energy renovations is carried out and which implications it has for practice.

The study of social and material relations during the design of energy renovations remain relatively unexplored in research since most studies attend to energy renovations from a techno-economic stance. Even if the techno-economic studies provide valuable insights into how energy consumption can be reduced from buildings, social science studies draw attention to the social interaction and material configuration of energy renovations (e.g. Gram-Hanssen, 2014; Palm & Reindl, 2018). However, little attention has been paid to how professional designers learn about and try to solve issues concerning energy performance during their everyday design practices (with a few notable exceptions, Berker & Larssæther, 2016; Gluch et al., 2018). This study illustrates how the design of energy renovations is both social, in the sense that designers negotiate the definition of design features, and material, in the sense that material objects enable designers to know about and act on the design. Drawing on the sociology of associations (e.g. Latour, 2005), this study argues that energy renovations are better seen as practical accomplishments based on social and material relations where the social and the material are mutually constitutive.

Energy performance is not the only concern that designers involve themselves with during energy renovations. Designers also engage in design problems concerning the stability of the buildings, the architectural design intentions, the project cost, acoustic considerations, technical installations, and much more. Because designers involve themselves in a plethora of different concerns, the many concerns and their spokespersons are likely to collide and create conflicts. In this way, energy performance competes with other concerns within the building design processes, and especially when a shortage of time and resources pressure designers, other concerns challenge energy performance and energy-saving measures risk being pushed aside. This study shows how energy-saving design ambitions need allies to support the interests in reducing energy consumption through design, or else ambitions of reducing energy consumption risk of disappearing from the project design. One way to achieve stabilisation in energy-saving ambitions is the inscription of the ambitions into material objects that act as anchors to hold energy-saving ambitions steady through the design processes. However, as this study shows, translation into material form does not ensure the mobilisation of other actors, and the other actors may betray the ambitions of reducing energy consumption in the buildings. Material objects provide stability to design processes; however, only temporarily and always with the risk of destabilisation.

The making of energy renovations depends on the everyday, material practices of designers. The everyday practices involve negotiations and engagement with material objects which both contribute to the definition and alteration of design features, including design features relating to the energy-saving ambitions in the projects. Energy renovations involve many different, sometimes conflicting, interests and designers negotiate design approaches, suggestions for solutions, and even the design problems through translation of interests, trials of strength, and attempts to persuade others. Acknowledgement of the negotiations happening in the course of design processes enables researchers to gain insights into how energy-saving ambitions change, transform, and perhaps vanish from the design processes. Material objects are crucial actors in the making of energy renovation designs. Inscriptions stabilise statements and design features across time and space which enables them to become resources in negotiations concerning design features. Material objects also inspire further inquiry, as when drawings raise questions and attract attention from the designers to unspecified and yet-to-be-known design features. This study also shows how material objects support the designers' learning processes by allowing the designers to explain design suggestions through acts of sketching. In this way, printed drawings materialise design features and enable negotiations between designers, as well as allow the designers to draw on top of the paper to extend the visible design features. Material objects can both provide enough information at the right times when the designers need the information, but they can also lack information and create confusion and hesitation among the designers. If research does not acknowledge the importance of negotiations and material objects in the making of energy renovation designs, then research risk overlooking vital mechanisms through which designers perform, create and alter energy-saving design features. Attention to the challenges and conflicts that designers meet in their everyday design processes is vital for the realisation of ambitions of reducing energy consumption in buildings.

Moreover, if we are to look at the practical implications, building designers should not take the design of energy-saving measures for granted but should take notice of how energy-saving design features enter energy renovation projects and how they change during the design processes. If building professionals expect energy performance requirements and specifications to remain the same throughout energy renovation projects, then professionals overlook the processes with which energy-saving design features change and transform through the projects. According to this study, relations between designers and material objects constitute the everyday practices that produce energy-saving specifications, and changes to these social and material relations may foster new ways of dealing with energy-saving ambitions. If building designers follow energy-saving design features closely throughout energy renovation projects, then they can prepare themselves for similar challenges as documented in this thesis.

The existing building stock needs comprehensive renovation if the energy consumption in buildings should reach political targets for energy savings. Realising energy renovations and constructing energy-efficient buildings involve rethinking all processes from project initiation and until the accomplishment of the construction work. All processes in between should embrace attention to how energy-saving ambitions can be achieved, including the practices of designing energy renovations. This thesis suggests appreciating the social and material relations that constitute energy renovations when embarking on such efforts.

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APPENDIX

Appe

APPENDIX

In the course of my PhD, I have attended conferences and research seminars. The appendix presents three papers with which I have analysed my empirical material. The first paper has been presented at the DEMAND Centre Conference in Lancaster, the UK, 13-15 April 2016. The paper explores the concepts of framing and overflow (Callon, 1998) in relation to my study. The second paper has been presented at the Design Research Seminar at Aalto University, Helsinki, 12 April 2017. The paper explores the concept of user representations (Hyysalo & Johnson, 2016) in relation to my study. The third paper has been presented at the 9th Nordic Conference on Construction Economics and Organization 13-14 June 2017 at Chalmers University of Technology, Sweden. The paper explores decision making as a take on my analysis.

TABLE OF CONTENT

Framing Energy Standards: The Role of Artefacts

Daniel Pihl, PhD student, Department of Development and Planning, Aalborg University, dpihl@plan.aau.dk.

Abstract

This paper investigates how building designers deal with energy requirements during planning of a renovation project. The study takes a practice approach to investigating design processes and is based on ethnographical fieldwork conducted by the author. The study suggests that energy standards, such as the low-energy class 2015 outlined in the Danish building code, do not get adopted as they are, but the standards are stretched and pulled by the stakeholders to fit interests in the project. Furthermore, the study discusses the role of artefacts in an engineer's attempt to enrol others in energy concerns.

Introduction

Existing buildings are seen by many researchers as well as practitioners as the key to reduce CO2 emissions. The existing building stock is responsible for 40 percent of the final energy consumption in Europe (Energy Efficiency Financial Institutions Group, 2015). There is great potential in reducing energy consumption in existing buildings. Up to 75 percent of the buildings today are build during a time period, where building regulations only required minimal or no energy-saving precautions (*ibid.*). In Denmark, the share of residential buildings is above 70 percent (Enerdata, 2015). The large amount of residential buildings with possible very low degree of energy-saving precautions means that there is a high potential of reducing energy consumption by renovating existing residential buildings.

December 2012 was the European Energy Efficiency Directive 2012/27/EU enforced and Member States were required to submit National Energy Efficiency Action Plans to the European Commission in 2014 (Enerdata, 2015). As preparation for the Energy Efficiency Directive introduced the Danish Energy Agency two new, optional low-energy classes in the building code (Danish Energy Agency, 2016). On 1 January 2016 became one of the energy classes, namely the low-energy class 2015, minimum requirement for new build (*ibid.*). The Danish building code require new, residential buildings to comply with an energy performance of 30 kWh per square meter per year, plus 1000 divided by the heated floor area. Additionally, the building code contains an optional building class 2020, where the total energy demand for the whole building must not exceed 20 kWh per square meter per year. When renovating residential buildings, the building code require energy improvements where it is cost-effective. When renovating a residential building, the building owner can choose to comply with the U-values and linear thermal transmittance stated in the building code, or to comply with an energy performance of 110 kWh per square meter per year, plus 3200 divided by the heated floor area (Danish Transport and Construction Agency, 2016).

This study investigates how energy requirements are accomplished on a renovation project during planning and design of the renovation works, and how various interests modifies the energy requirements. As a standard must all buildings comply with minimum requirements in the building code, but this study examines the making of the specific requirements on the renovation project. I take on a practice-based approach supplemented by concepts from the sociology of translation to investigate the present study.

Theoretical framework

This investigation stems from an interest in practice and how work is ‘accomplished’. Inspired by an ethnographic approach, my interest revolves around how stakeholders perform certain tasks on a renovation project. My interest especially concerns how stakeholders produce materials and objects and strategically use them to convince people about something. As point of departure, I take practices, which allow me to get descriptions of how the stakeholders produce and circulate materials relevant for the issue at hand. Here I will elaborate on the theoretical frame of this study. The study builds on a practice-based approach by adopting concepts from the sociology of translation. First I will sketch out some of the features in a practice-based approach, and afterwards, I will outline some of the concepts I use in my analytical description.

The study of practice has been developed into several approaches among research scholars over the years (Nicolini, 2012). The approaches have been labelled practice idioms, practice standpoints, and practice lenses, and all imply a sensitivity towards seeing the world routinely made and re-made in practice using tools, discourse, and human bodies (*ibid.*). By taking a practice standpoint, researchers are able to highlight the mundane work activities among professionals. Focus of such a standpoint is especially on mundane routines and conflicts, because it is in these situations that displacements and interests unfold. Practice approaches take on a processual view on organisational matters, which practice-oriented scholars study by examining various ways of ordering.

The approaches contribute with a sensitivity towards the continuous routinization and re-emergence of various accomplishments that establishes and maintain work practices.

> *"The great promise of the practice lens is that of explaining social phenomena in a processual way without losing touch with the mundane nature of everyday life and the concrete and material nature of the activities with which we are all involved." (Nicolini, 2012, page 9).*

One central aspect of the current study is the role of artefacts and materials in practices. Practice-oriented approaches have always been attentive to the material dimension of practices. Knowing is seen as a social and material activity. For example, Gherardi and Nicolini (2000) suggest that organisational knowledge is relational and mediated by artefacts. Seen from a practice perspective, knowledge cannot be separated from the artefacts. The only way knowledge can be shared with others is if the knowledge is performed through a set of practical methods involving inscriptions in objects, human bodies and discourse, which only can be partially articulated (Nicolini, 2012). When it comes to objects, materials and technology, Nicolini argues, then they need to be studied 'in practice' and with reference to the practices in which they are involved. Even if practices are performed in isolation, without any contact to other humans than the one performing the practice, then the mediation of materials, objects and technologies still situate the practice historically and make it a social phenomenon. The social is then mediated by the objects and materials.

Taking a step further into the mediating role of objects and performativity of materials, the sociology of translation (ST) is proposing another type of sensibility in the study of practices. The sensibility proposed by ST scholars is to notice the messy practices of relationality and materiality of the world (Law, 2009). Material entities are not just part of our practices, but also change our practices when humans are confronted with the material entities, also called nonhumans (Latour, 1988). Nonhumans are delegated characters that play a certain role that can imply a certain political interest. From an ST perspective, nonhumans are not just tools for human action, but nonhumans imply certain political interests and can possibly discriminate certain actions from humans, as well as from animals and other actors. Additionally, by adopting an ST lens, knowledge always takes material form. Law (1992) give some examples on how knowledge constitute material entities, such as talk, conference presentations, papers, preprints or patents. Material arrangements are therefore important aspects of knowledge production as well as work practices.

The underlying assumption with regards to material entities is that materials are not passive components of our work practices, but some materials are being used actively to convince others about the importance of certain concerns. Callon (1986) describes this process as translation and sketch out four moments of translation, where actors undergo various persuasion mechanisms. If the persuasion is successful, an actor is able to mobilise other actors in his or her project. Translation is a key concept in ST and involves the definition of actors by the circulation of intermediaries among those actors involved (Callon, 1991). Intermediaries play a vital part in the definition of actors, because actors are defined from what they do or what they put into circulation.

> *"Actors define one another by means of the intermediaries which they put into circulation." (Callon, 1991, p. 140).*

An intermediary is something or someone which/who transports meaning or force without transformation (Latour, 2005). Intermediaries do not do anything. Their input is their output. Mediators, on the other hand, transform, translate, distort, and modify the meaning or the elements they are supposed to carry (*ibid.*). Mediators are defined by what they do – because they do something. Most of the time, mediators are the interesting entities to observe, because they shift and displace actors, ascribe roles to others or allure others to act in certain ways.

Another aspect of the present study is the agreements made on the renovation project among the stakeholders and what the stakeholders expect from each other. To explore this aspect, I draw on Callon's (1998) notion of framing, which he borrows from economic theory and extends to sociology as well. Framing is the process in which stakeholders agree on a frame within which their interactions will take place and which courses of action that are open to them. For a period of time, the stakeholders are interconnected by expectations set in the frame to how the role of each participant is expected to be. But sometimes the agreement fails, leaving the frame impossible to achieve or the frame is deliberately transgressed by the actors, leading to overflows (*ibid.*). Overflows leave the frame permeable to the world outside. Callon argue that the constructivist sociology view of overflow is that they are omnipresent and that framing is rare and expensive to establish. The notions of framing and overflow will be elaborated in the case.

Case description

This article is based on an on-going ethnographic study investigating what happens when energy requirements 'come into' design and planning of energy renovation projects. The empirical basis of the study is fieldwork conducted by the author in the course of six months, beginning in August 2015. The author followed architects and engineers in planning and designing renovation of four apartments blocks located in a suburb to Copenhagen, Denmark. The client, a social (non-profit) housing association, emphasizes that the project in question is an 'energy renovation project', because the aim is to lower the buildings' energy consumption more than required in the existing building code. In going beyond compliance, the client in this way deems the project to be ambitious project energy-wise. The buildings being renovated are all rented out by the housing association. Within housing associations of this kind involving the residents in the design and planning of the project is mandatory. So the client has gathered a steering group of residents to follow the project from initiation until they move into the new apartments.

The design team consist of employees from an architectural office and an engineering office. The architectural office won the renovation project through a competition in 2013. After the competition, the engineering company became subcontractor to the architectural company in delivering the renovation works. The overall distribution of responsibility between the two companies is that the architects focus on conceptualising the project in the early design phases, while the engineers are to focus on the phases detailing the project and the tendering process. As a consequence, the architects' influence is strongest during the disposition phase in which the project proposal is further developed, whereas the engineers focus on detailing the building installations in the main project phase. During my fieldwork, the project went from being in the project proposal phase, to approval of the municipality, and further to the main project phase. The engineering company provides different engineering services and expertise within ventilation, pluming, construction, electricity, fire regulations, acoustics, as well as energy and indoor environment. Additionally, the engineering company had in 2013 bought up an architectural company so that they could also deliver architectural services. As a result of all the competences gathered in the engineering company, the company hosts the design meetings in the renovation project, because it is easy, when needed, for the design team to fetch people with the necessary technical and architectural competences for the meetings.

The renovation project involves planning renovation works for four apartment buildings. Additionally, the client has chosen to extend one of the building block in the length with an extra staircase, plus extending every housing block in the height by an extra storey. This means that the project both involves renovation works and new build. The project has to comply with both requirements in the building code for new build and renovation, which makes the project complicated. As a way to go around this complication, the design team chose to make sure that the design specifications they follow both comply with requirements for new build and renovation. Initially, the client wanted the building to comply with passive house standard, but this was later on deemed by client consultants (other than the current design team) to be expensive. So instead, the client asked for compliance with low-energy class 2015.

The fieldwork was carried out as non-participant observations during a selected number of design meetings and through semi-structure interviews with key persons, identified by the author. The purpose of the observations was to register how design choices were made and to see if and how energy requirements influence changes in design. Four meetings were observed, all design team meetings, meaning that both architects and engineers were present. The meetings took place in August and September 2015, as well as in February 2016. By being present at these meetings allow me to register the interactions among stakeholders as well as their material objects. For the purpose of the study, an interview with the engineer responsible for energy-related issues in the renovation project was paramount. A second interview has been conducted with a representative of the client to get an insight into the client's motivation for raising the bar with regards to the targets for the renovated buildings' energy performance. The choice of making the renovation ambitious was, however, not made by the client alone, but was made together with the municipality and a steering group consisting of residents. The interviews lasted approximately one and a half hours, while the design meetings sometimes took up whole days. The meetings were recorded by taking notes, which were re-written after the meetings to keep details from the situations and add bodily gestures and other impressions from the meetings. The interviews were audio-recorded, and the parts pertaining to energy-related issues were afterwards transcribed.

Analysis

The analysis is presented in three parts. Firstly, I will investigate how the design team members frame energy requirements, and how their practices lead to various overflows. Secondly, I will look into how the engineer with responsibility for energy concerns on the project try to convince the other team members in following the energy specifications, he set out. Thirdly, I will elaborate on how various project concerns are interwoven and influence each other.

Framing and overflows

In the renovation project, the building owner and the building consultants have agreed to lower the energy consumption of the existing building corresponding to the low-energy class 2015. In the present part of the analysis, I look at how the stakeholders are framing their mutual agreement about reaching low-energy class 2015. First, I will elaborate on the framing of the compliance with the energy requirements on the project, and afterwards, I will elaborate on some overflows that have happened within this framing.

Callon (1998) talks about 'bracketing' when actors perform framing. Bracketing means that the actors close out the outside world and agree upon certain terms in which their interaction should be led. Simultaneously, the outside world is not totally cut off, because the outside world still has some bearing on the agreements. In the case of the renovation project, the connection to the outside world is for example the energy requirements in the building regulations. As the quote underneath indicates, the renovation project is required by law to comply with certain U-values, as well as airtightness and integration of ventilation system with heat recovery. But in the project, the participants agree on complying with low-energy class 2015 and a bit more, which indicates a 'bracket' compared to the requirements, they otherwise should comply.

> *"Building code 2015 has some requirements for new build, but also has some requirements for renovation. And requirements for renovation are all about U-values." (Interview with engineer, February 2016).*

The requirements have over the course of the project changed: First to low-energy class 2015, then to energy class 2020, and then a hybrid between the two classes. The shifting between energy classes was due to estimates of the costs tied to achieving them. First, 2015 was deemed by the client to be sufficient, but then they saw a possibility to achieve 2020 on the whole building. After negotiating with the design team, the energy specification landed on a hybrid between 2015 and 2020. During his investigation of the energy requirements on the project, the energy specialist from the design team brought the notion of passive house back into the project. The passive house standard was initially the wish of the client in early project stages, but was turned down because it was deemed to expensive. The fact that the engineer brought the passive house standard in again has, in his opinion, pleased the building owner. The two documents, or actors, the building regulations and the passive house standard are two links to the outside world, which for a while set some of the conditions for the framing.

A part of the framing was the mutual agreement of having an energy specialist in both camps: One sitting by the building owner and another sitting by the design team. Each energy specialist was chosen internally by the building owner's organisation and the design team's organisation respectively. The role expected by them was to address every energy-related concerns in the renovation project. The design team for example, waited the design team members for the energy specialist to enter the project team, before investigating the energy-related concerns in depth.

"We could easily end up making a Be10[9] [calculation], regardless of its limitations. Because that is what the Danish Building Research Institute says is alright. And if they say that it is alright, then our back is covered. Then we have done what can be expected of us and what can be required from us." (Interview with engineer, February 2016).

The design team members want to make sure that they comply with the building regulations on energy matters, but also that it is possible to achieve low-energy class 2015 or higher. The other design team members had similar expectations of energy specifications based on their previous experiences on similar renovation projects. Another example of how previous experiences play a part in the framing of energy requirements is how to estimate the number of days with high indoor temperatures in the apartments. Even though, there is legitimate calculation methods to 'prove' how many days the occupants will feel high degree of heat in their apartments exist, the energy specialists are 'allowed' to base their assessment on assumptions and previous experiences.

"Fundamentally, we estimate ourselves from our experience with other similar buildings; where will we get problems with high temperatures?" (Interview with engineer, February 2016).

The framing of interaction is sustained by some kind of physical framework, for example the building, stage and curtain in the framing of a theatrical play (Callon, 1998). In the case of the renovation project, the physical framing of energy-related concerns is visible in the detail drawings. During planning of detail drawings, the project participants make space for energy-related concerns. They know that they should make room for a thick layer of insulation and a massive tin box of a ventilation system, because they are parts of the means to reach low-energy class 2015. Therefore, the physical framework of the energy-related concerns is also, to some extent made visible in the work of the design team.

In the above section, I have outlined some of the artefacts - calculations and drawings - that it seems that the project participants have framed their interaction in regards to energy-related concerns. In the next section, I will elaborate on some of the overflows from the framing that the project participants have experienced.

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[9] Be10 is a software programme for calculations of energy demands in buildings. The software is developed by the Danish Building Research Institute and the Danish building code refer to the software when specifying how to document compliance with the energy requirements (Danish Transport and Construction Agency, 2016).

One of the aspects in the clients' framing is the handover of responsibility for energy-related concerns to energy specialists by the other project participants. But the energy specialists were only involved in the project very late. Leading to 'bad' decisions, seen from their point of view.

> *"According to me, somebody should, when they first came up with this fantastic idea for the statics, that they then had sat down and analysed, 'okay, what do we do then? What is it that can be done?'" (Interview with engineer, February 2016).*

The late involvement of energy specialists has, in their understanding, a negative effect on ensuing design decisions. The decision, for instance, to have concrete columns in the architectural expression of the façade has a great impact on the 'energy efficiency' for the façade as a whole.

Another issue creating an overflow is the shifting of energy targets required from the building owner. During the course of the project, the energy targets have changed from passive house to low-energy class 2015. Even though this appears well-defined – with 30 kWh per square meter per year – this requirement can be interpreted in many ways.

> *"There has not really been any clear passage on what the energy requirements have been on the project. They [the client and residents] have referred to the building regulations for 2015 for example. And as you can see, I have quoted them for writing 'roughly' or 'on par with' 2015 without specifying anything fully definite what it is about." (Interview with engineer, February 2016).*

This lack of accurate energy targets has contributed to a confusion among the design team members how to comply with the requirement set out by the building owner. During framing, members often establish rules within their interaction have to follow and what is expected of them (Callon, 1998). In this case, the rules are vaguely co-produced together with building owner and design team and therefore lead to confusion on the renovation project.

> *"Framing cannot be achieved by contractual incentives alone, because it is bound up with the equipment, objects and specialists involved in the interaction." (Callon, 1998, page 255)*

As the quote above indicate, framing is not only established by means of contractual arrangements, but is being hold together by the actors and their interests involved.

Mobilisation of design team members

The engineer with responsibility for energy and indoor environment noticed when he entered the design team that the definition of energy requirements on the renovation project was not as clear as he had expected. From his point of view, if the design team wanted to make sure that they comply with the energy requirements set out by the client, then the team had to develop some more concrete requirements. Instead of talking about complying 'roughly' with low-energy class 2015, then they in the engineer's view needed some more exact figures to work with.

> *"There have been various intentions during the project. The purpose of this note was actually to hold on to – okay, what is it that we do?" (Interview with engineer, February 2016).*

The engineer not only produced a note, but he also convinced the other members in the design team, as well as the client, municipality and residents, that his suggestion was the way forward. He circulated the note among the relevant stakeholders for their approval and in this way shifted the stakeholders' framing of the energy requirements. The note was acting as an immutable mobile (Latour, 1987). Their framing went from references to low-energy classes 2015 and 2020 to concrete figures indicating U-values of building components, airtightness and degree of heat recovery from the ventilation system. In the quote underneath, the engineer explains how the other design team members reacted on the note, he had written.

> *"They said, 'then, let us present it for the client and for the municipality.' And then we presented it [the note on energy requirements] for the client, and afterwards for the municipality. 'Well, you should just be aware that we want to be ambitious with regards to energy targets.' When I presented the note for the construction engineer, he said, 'it cannot be made. We cannot make a façade with 0,15 in U-value on this project.' So I had to knock that one down as well. And then we take it [the discussions] continually." (Interview with engineer, February 2016).*

The engineer not only circulate his description of the concrete energy requirements, but also explanations of how to achieve for example the U-values, he has concretised. In the quote above is the construction engineer not fully convinced, but the energy engineer confident to convince him at some point. The note in this example is produced with a view to shift the framing of the design team members and mobilise them in the interests of the energy engineer.

Interwoven design concerns

The thing that receives most attention from the design team during design meetings is the detail drawings. A detail drawing is a junction of various design concerns gathered in one drawing. The procedure for talking about any detail, be it how ducts are passing through a wall or how static forces from the roof is running through the exterior wall and down to the foundation, is to go through the conditions for the detail at hand. Every designer, who wants to move the other participants' attention to some issue, begin to draw up the conditions surrounding the issue. If we take the ducts passing a wall, mentioned above: First the architect, for example, draws the wall and note that it is a concrete wall. Then the next solid condition, a concrete structure for flooring, which rests on the concrete wall. In this way, the static and structural conditions are highlighted. Possibly, the architect draws a line in another colour around the wall and flooring structure just to indicate the interrelatedness between them. The architect then draws the suspended ceiling and indicates the space for ventilation ducts going on top of the ceiling, but underneath the flooring structure. This way of presenting design issues to the other design team members is a common one on the renovation project studied here.

The procedure on presenting design issues is an example of how architects, and engineers for that matter, zoom in on an issue and in the next moment zoom out to consider the whole building. This movement is studied by Yaneva (2005) in architectural practices. An issue is never an isolated entity. Opening up one issue often lead to a myriad of associations to other issues and concerns. In the quote below, an engineer is telling about how an issue concerning penetration of the insulation material in the exterior walls can, from his point of view, lead to low U-value for the whole wall. As the quote indicates, dealing with insulation material in the exterior walls is not only an energy-related concern. Statics, architectural visions and constructional details also play a part in the issue.

> *"There have to be some columns and which should give a certain [architectural] expression in the façade. It is not all of the columns that are needed constructively speaking, but they must be kept in place anyway, and there must be some foundations and stuff like that. The balconies have to suspend from the facades. Which means that the forces must be partly led into the house. In the existing walls. That is, there have to be some mountings, which go through the insulation. It should be designed so there will be as little as possible heat loss through them. It would be something like sitting with the construction engineers and sketch on it. Telling them that stainless steel is better for the penetrations than ordinary steel, because they channel the heat worse." (Interview with engineer, February 2016).*

The procedure for presenting and discussing design issues among the design team members shows how various concerns on the renovation project are interconnected.

Discussion

This study examines architectural and engineering practice during planning of a renovation project, and role of artefacts in setting energy specifications on the project. But how can we understand the role of artefacts in architectural and engineering practices? For starters, we have seen that the energy specifications presented in the Danish building code is prone to interpretative flexibility (Pinch & Bijker, 1984). Design team members frame the requirements differently and the targets for final energy demand in the building have shifted during the course of the project. Artefacts play an important part in the shifting and displacement of energy targets, but how can we understand their role? On basis of the current study, the artefacts take on various roles as either intermediary or mediator. For example, the Be10 calculation, which was only briefly mentioned above, play out as an intermediary in the establishment of energy specifications. The building code refer to the calculation method, but the interviewed engineer express that it is has its 'limitations'. In this way, he disregards the software as being able to help them define the energy specifications on the project. The calculation could be used for showing that the project complies with requirements in the building code, but it does not seem to shift the engineer's view of the energy targets on the project.

Other artefacts play another part. They shift and distort the framing of the design team. Two examples are the detail drawings and the note produced by the engineer. These two artefacts transform, to some degree, the design team's idea of the energy targets. During planning of the renovation project, detail drawings play a vital part for the design team members, because the drawings gather various project concerns and relate them to each other. When the design team members are discussing a detail, insulation thicknesses or performance of ventilation systems are brought forward. Either they refer to the engineer and his speciality, or they discuss how it could be constructed. The detail drawings change the design team members' attitude towards energy concern, but also other project-related concerns. Another important artefact in this story is the note that the engineer produced. The note specifies the energy targets that the design team wants to achieve. The note shifts the design team members' approach to the energy requirements set out by the client. The note makes the requirements more concrete and the design team members can easier relate to them. After mobilising the others in accepting the note as the way forward on the project, the design team, and the client for that matter, all can turn to the note if any confusion about energy targets arise. The note has become a spokesperson (Latour, 1987) or obligatory passage point (Callon, 1986) for the energy concerns on the project.

These findings indicate that energy standards are not just adopted on the renovation project, but artefacts as well as people transform them as they incorporate them into their project. Like many other project-related concerns, the energy concerns have to be modified to the current project conditions. So how can we understand the role of artefacts in establishing and continuously transforming energy targets on renovation projects? Which constellations or webs of people, artefacts, competences, contractual arrangements, building codes, and much more constitute these energy demands?

Concluding remarks

This study suggests that artefacts play an important role when building designers frame energy requirements during planning of renovation projects. As mediators, artefacts shift building designers' framing of energy targets and establish connections between energy-related concerns and other project-related concerns. If we want to understand how energy demands in renovation projects are established and transformed during the course of the projects, then we have to be attentive to how artefacts and people interact. This study recommends further research in the area of design practices and the role of artefacts within the construction industry.

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Studying User Representations on Energy Renovation of Social Housing

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Abstract

The purpose of this draft paper is to discuss how to study user representations in empirical cases and present preliminary analysis on a case from the building industry. The study investigates how architects, engineers and tenants produce, make use of and circulate various user representations while designing an energy renovation project of a social housing estate in Denmark. My ontological and epistemological approach is inspired by Actor-Network Theory and I identify three categories of user representations which will inform my analysis. The analysis is based on fieldwork during project meetings and everyday design work which include video observations, interviews and document analysis. The findings (so far) identify two types of user representations, which are briefly explored. The next step of analysis would be to keep exploring how user representations are treated on the building project and start to describe any possible controversies.

Introduction

Representations of users in design processes have been studied through decades. Hyysalo and Johnson (2016) recapitulate on studies of envisioned users until today and identify eight areas of sources in which representations of use and users enter the design of technological innovations. The source areas include techniques for involving users and gathering user requirements, the designers taking the place as a user (or a citizen) and their professional view on users, implicated users in business concepts, user representations in regulatory demands, implications on use from earlier developments of technologies and a general cultural maturation of our societies (*ibid.*). The purpose of the present draft paper is not to give an exhaustive account of how users have entered design processes in the literature, on the contrary, the purpose is to present and discuss how we as researchers can study user representations in design processes based on an empirical example.

The field of science and technology studies (STS) has a particular view on interaction between users, designers and technologies. Opposed to linear views on technological innovation and ideas of innovation as only happening in research and development departments, new technological developments seem to be affected by how social groups interpret and interact with technological artefacts (Pinch and Bijker, 1984). Technologies and groups of users are being socially constructed by their interaction with each other. Not only is the identity of users being constructed and changed over time, but users are being "configured" by designers when they enable possible actions the users can take (Woolgar, 1990). Configuration or standardization can be so powerful that some users are pushed out of the "target group" and become "as-yet unlabelled" users or non-users (Star, 1991). Studies also show that designers "inscribe" visions about use, users and the context in which use is envisioned to happen in the technologies they develop (Akrich, 1992). Nevertheless, use of technologies do not always (or it might be rarely) conform with visions inscribed by the designers, and users might find completely other ways to use the artefacts or use them in situations and in ways not foreseen by the designers (*ibid.*; Latour, 1988). Even when technologies are passed around in the hands of different users, the identity of the technologies (and the users for that matter) become different variants of user-technology relationships (de Laet & Mol, 2000). How technologies seem to "work" depends on how users take the technology up and pass it around (or not). Furthermore, the relation between designers and users has been placed under scrutiny, and it seems that designers, as well as users, are being "configured" by their organizations and by users (Mackay et al., 2000). Even researchers are highlighting potential uses of their research, but the user seems to be fabricated by researchers as a device to invoke potential value and hopefully receive funding for their research (Shove & Rip, 2000).

The studies above are only a few pointing to the importance of studying user-technology relations. Next to the studies, authors have also collected studies in anthologies (e.g. Oudshoorn & Pinch, 2003a; Hyysalo et al., 2016). All these studies draw on many different empirical fields and take different approaches to users. What they all seem to agree is that the relationship between design and use of technologies are important to understand how technologies and society co-develop. This paper taps into this interest and give an example from the building industry.

Empirical case and methods

This study investigates how designers produce and treat user representations during design of a renovation project. The project revolves around the renovation of four building apartment blocks rented out as social housing. In the following, I briefly describe the project.

In 2013, an architectural firm won an architectural competition. The aim of the competition was to encourage development of sustainable buildings concepts in the

Nordic region. The competition involved an open call for international and multidisciplinary teams to suggest renovation of five predefined building estates – one in each Nordic country. The architectural firm suggested the renovation of a social housing estate in Denmark. The suggested renovation project by the architectural firm and their partners is the empirical case of this study. The case consists of four multilevel apartment buildings which surrounds an inner common space with green areas.

The apartment buildings are rented out as social housing, and in accordance with Danish law on social housing, a board of tenants are responsible for the daily management and financial governance of the estate. All tenants living in the estate have the right to influence the agenda of the board if they have concerns they would like to raise. Five people, out of seven, from the board of tenants are actively involved in the renovation project and take decisions related to their area of responsibility. The board of tenants together with the housing association, which manages several social housing estates around Copenhagen, act as the building client. Before the architectural firm, the board of tenants and the housing association were able to develop and specify the renovation project, the tenants living in the estate had to vote whether to accept an increase in the rent and to proceed with the proposed renovation, or decline it and keep the estate as it was. In January 2015, the tenants voted in favour of the renovation project and the design and planning of the renovation works could officially begin.

The aim of the renovation project is to modernise the apartments and attract more families to the area. The project involves merging of apartments into fewer, but larger apartments, as well as replacement of facades with new and high-insulating building components, and establishing penthouse apartments on top of the existing building blocks. Additionally, the green areas around the estate will be transformed by landscape architects. The buildings were built in 1962-63, and today, the existing buildings are time-worn and have problems with mould, which might have originated from an earlier renovation in 1992. The estate is in a strong need of renovation. Several of the stakeholders are interested in lowering the energy consumption of the buildings as much as possible and therefore call the project an "energy renovation". The board of tenants want to lower the energy bill for the themselves and the rest of the tenants living in the buildings. The housing association and the municipality both want to brand themselves as being forerunners on the carbon-neutral agenda.

Fieldwork was conducted from August 2015 until January 2017. During this time, the renovation project moved from schematic design, over design development and to construction documentation for bidding from contractors. I followed project meetings and conducted two interviews during the early design phases. In the later design phases, during the later design phases, I observed project meetings and daily work routines 3-5 times a week. Meetings were either recorded as sound or video and interviews recorded as sound. Documents and drawings have been gathered to the extent it was possible, and pictures have been taken during observations. I chose to follow project meetings in hope of observing design discussions across professional disciplines. I also participated in meetings between designers and tenants, where design decisions related to the tenants, the housing section or the housing association were discussed.

The importance of studying users in relation to energy consumption in housing

Buildings account for around 40 % of the energy consumption of Western countries and lowering the consumption in buildings could lead to achievement of political goals about carbon emission reductions. Most of the literature on energy consumption in buildings focus on the technical side of the buildings or take an economic approach in studying consumption, but some researcher acknowledge that the behaviour of users has a great impact on the energy consumption (Guerra Santin et al., 2009; Gram-Hanssen, 2010). While these researchers study houses while people live in them, there seems to be a lack of awareness on how designers prepare buildings for low-energy consumption and which role users play in this endeavour.

Studying User Representations

In this section, I present three types of user representations which constitute my analytical framework. The first group of user representations is people "in the flesh" that place themselves in the position as "the future user" in certain actions, no matter if it is professional designers or tenants who are taking this position. The second group is nonhuman actors, such as drawings, simulation tools, standard documents or regulatory demands, which represent the user in certain ways. The third group is representations of users who are excluded or absent from design activities, but are still deemed important by informants or research on the relation between occupant behaviour and energy consumption. In the following, I elaborate on the three categories.

User representations "in the flesh"

In design of technologies, designers do not always know who the future user is going to be. Because the technology is not yet designed and produced, the designers cannot observe and interact with the actual users. Instead, designers sometimes observe people whom they think might be the future users (like studies on market and customer research show), or they invite people into the design activities and let them represent the future users (as shown in studies on participatory design, co-design, and human-computer interaction). These users have been called "lead-users" (von Hippel, 1988), "proto-users" (Yaneva, 2009) and "proxy users" (Stewart and Williams, 2005; Stewart and Hyysalo, 2008), and they "stand in for" the future user in particular situations. In the present case, a handful of tenants is involved in the design and planning of the renovation project. They do not "stand in for" the future user all the time, but in few situations, the tenants stand proxy for how the future users will use energy-consuming technologies and which preferences for indoor comfort the future users would have. Designers can also be seen as proxy users. Similar to the five tenants, designers can take the position of future users. Designers can rely on personal experience and changing role from being a professional to being a user (Akrich, 1995). Besides referring to the designer's own experiences, the designer can also refer to oneself as means to articulate future usage (Hyysalo, 2010). This category of user representations point to human actors, but understanding agency as distributed among human and nonhuman actors, I will in next section turn to a category pointing to some nonhuman actors. Designers and users are capable of envisioning technologies and their use because they are immersed in an environment filled with nonhumans. People are only capable of certain activities because they are equipped with "prostheses" that allow or reject certain actions (Callon, 2004). If you remove the paper, pen, simulation tools, email, sketches and similar nonhuman actors from the architect, the architect is not able to do the same kind of work as with these "prostheses". Therefore, I now turn to the category of nonhuman actors.

Users represented by nonhumans

In architectural practices, designers are surrounded by nonhumans contributing to their work, such as scale models, drawings, sketches, paper cut-outs, foam models, program diagrams, scale models, and so on (Yaneva, 2009). For example, perspective drawings depict certain social configurations and project potential uses of buildings and spaces (Houdart, 2008). Some studies have also investigated how practices of using information and communication technologies develops together with the use of papers, pens, rulers and other non-digital artefacts (Harty, 2005; Harty & Whyte, 2010). Computer models and simulation tools can therefore also be seen as nonhuman actors. In relation to simulation tools which calculate buildings' energy consumption, researchers are discussing how to incorporate occupant behaviour in the simulations in different ways (Guerra-Santin & Silvester, 2017). In this way, simulation tools can also become representations of users by the assumptions that are programmed in them. Another type of nonhuman which plays a role in design of energy renovations is the energy requirements in Danish building code, which also have assumptions about users in them. The last type of possible nonhuman that I want to mention is standards. Standard documents can act as intermediaries that enforce certain design conventions and thereby excluding debates over use of technological artefacts (Harty, 2008). Standard documents and procedures can therefore also represent certain uses of technologies. Based on the above, I analyse drawings, documents, standard procedures, regulatory documents, simulation tools, and similar nonhumans in order to investigate whether they are representing energy-consuming usage of the buildings.

Representations of the excluded or absent user

As indicated by Oudshoorn and Pinch (2003b), non-users seem also to matter in technological developments when users resist technologies on different grounds. This last category of users explores when users are not being represented. The lack of representation could stem from deliberately actions made by actors in order to prevent some users of entering the design activities. These actions of exclusion will lead to ignorance of some users, and can be deemed unfruitful for some practitioners or researchers. On the other hand, the users themselves could also choose not to participate and be represented. The active decision of not partake in design activities could be a way of showing rejection of the design project. In order to study these users, I explore how the particular designers in the case mention energy usage which is important and then compare if they somehow incorporate this aspect into their design activities. In the same manner, researchers have studied Post Occupancy Evaluation data and identify areas that affect energy consumption (see for example Menezes et al., 2012). These studies could also point to energy-consuming usages which might not be handled by the designers.

Preliminary analysis

In this section, I present my recently started analysis on user representations in the design activities related to the aforementioned renovation project. The following descriptions are therefore the early beginning of my work on understanding relations between different user representations in the case. As I understand the guidance presented by Latour (2005), I will approach my analysis in three steps. First, I identify groups of users by locating spokespersons of these user groups. As Latour writes, when groups start to form usually these groups dissociate themselves from other groups, and therefore, groups and “anti-groups” are formed in the same time. When identifying user groups, I rely on my previous categorisation of user representations in human and nonhuman actors, as well as excluded or absent users. Second, I identify controversies between different groups or spokespersons. Third, I trail the controversies through my empirical material and describe the various trials of strengths. This approach should give an idea of how user representations have been treated in the design processes. The rest of this section will focus on the first part, namely identifying user groups on basis of the user categorisations presented, and because the present analysis is still in progress, I will focus on two types of nonhuman actors.

How users are represented by standards and regulatory demands

Use of the buildings relating to energy consumption is represented by two types of nonhumans, namely the standard called Passive House and the energy requirements in the Danish building code. I will first describe which role the Passive House standard has played on the renovation project, and afterwards, I will describe how users could be represented by the energy requirements.

The Passive House standard was a reference the board of tenants gave in the beginning of the renovation project (three years before the architectural firm and partners won the competition). At that time, the tenants wanted lower energy bills and a good indoor climate, so they asked for the renovation to comply with Passive House requirements. Later in the project, some advisors on the project deemed Passive House too expensive compared to the indoor climate the tenants could achieve. The same indoor climate could be achieved by less requirements. So, the Passive House standard was taken out of the project and replaced with requirements referring to the Danish building code instead. Even though the Passive House standard went out of the project, the engineer with speciality in energy and indoor climate brought it back into the project. He made a note stating that both the requirements referring to the building code could be met, and the Passive House standard to some extent. So, during this time, the concept of Passive House was participating in shaping the energy requirements on the project and became part of two nonhumans: A briefing document from the early beginnings of the project and a note written by the engineer in the middle of the design process.

The Passive House standard has been used by the participants to indicate that they are ambitious in regards to energy performance of the buildings. If one looks into the standard then the houses are described as being very technical and have some restrictions on use. For example, the low energy performance is achieved by high level of insulation in the building envelope and windows which gain heat from the sun. The heat from the sun is then regulated by sunshade and ventilation system. Designing houses with large windows means that the houses can be warm more or less by the sunlight. The word “passive” refer to very little energy is needed to heat up the houses. The downside of this is that the occupants must adjust themselves to letting the technical equipment manage the indoor climate. Meaning, less airing out, because the ventilation system will take care of that.

The other type of nonhuman, or actually, several actors are involved, is the energy requirements in the Danish building code. According to the code, stakeholders can either ensure the right U-values (degree of insulation) of the building envelope or calculate an energy performance when renovating existing buildings. The engineer mentioned before agreed with the municipality and housing association to comply with the U-values, but even though, the other people on the project talked about the energy calculation still. The engineer was hired on several projects while working on this renovation project, so he was not present all the time. And when he was absent, the other designers asked each other whether they comply with energy requirements and what the energy calculations show. The rest of the designers never got to see the energy calculations, but they told each other that it was made by the engineer.

The Danish building code refer to a simulation tool called Be10 (short for "building energy simulation" and the newest version is called Be15, but the designers talked about Be10). The simulation tool is a method for stakeholders to show that their building project comply with the energy requirements in the code. In the software program, designers type in different values in order to calculate the energy performance, and many of these values refer to occupant behaviour. For example, how many hours people are home, how many people live in the building, how much water they use per year, how much electrical appliances they have, and so on. The software contains several assumptions about user behaviour. The Danish Building Research Institute has designed the programme and has also made a manual, where they suggest different values for designers to enter in the programme. These suggestions plus the possibilities given in the programme represent the occupants in different ways.

The next step of my analysis is to dig into these two types of nonhuman actors, and other actors, in order to see how they are treated by the designers and tenants. For now, the above is a short introduction to some possible user representations, which could be elaborated on more.

Discussion

The purpose of this draft paper is to discuss how to study user representations. I have briefly gone through my approach above and given two short examples, which need further exploration. What I have not presented yet is what I mean by "representation". How do something or somebody represent something or somebody else? In this case, I do not mean representation as in the democratic sense, because then the board of tenants would probably be the focal point, if that was the case. Neither do I mean the relation between "signifier" and "signified" as described in linguistics and semiotics. What I have tried to show is representation where things, people, values or concepts stand in for use.

I am trying to avoid attitudes or opinions about users and tried to observe when a user representation is being practiced. For example, when the engineer type in a value about water consumption in the software mentioned above. Then the value stands in for the future users. However, can we look at representations in other ways?

Users can be presented in many different ways. Users "in the flesh" as I described above is one obvious way, but when, for example, the tenants represent future usage of energy-consuming technologies is not so evident. When do we for example talk about opinion compared to "representation"? Users can also be represented by nonhuman actors. Here researchers could use the same literary instrument as Woolgar (1990) used to show the relation between "reading" and "writing" technologies. Nonhuman actors can therefore refer to specific users or uses. Then the question becomes how are these nonhumans created, handed along, treated and transformed during design processes. User can be implicated in many areas of design work, but how to locate the different implicated uses?

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The role of objects in decision-making processes: The case of an energy renovation

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Abstract

Most studies on decision making in construction projects suggest theoretical models or conceptual methods for how decisions ought to be made or which concerns or issues to include, but the number of studies which examine 'actual' decision-making processes are relatively scarce. This study reports on field work done in an energy renovation of a social housing estate in Denmark. Based on interviews, observations, and a document study, a decision-making process is reconstructed in regards to the choice of either installing a centralised or decentralised mechanical ventilation system in the buildings. The study focus on how participants try to convince each other by mobilising different objects and therefore contributes to discussions on which role objects play in construction projects. Two types of objects were mobilised in the pursuit of convincing others, namely a note written by an engineer and two decentralised ventilation units presented by scientists from the Danish Technological Institute. The latter was presented as having most impact on the decision, which meant installing decentralised ventilation in the buildings.

Keywords: Decision making; energy renovation; objects; actor-network theory;

Introduction

Decision making in construction projects has gained a lot of attention in academia. A great number of studies are approaching decision making by trying to explain how the processes should be done or what kind of topics or issues to include when confronted with decisions. For example, Ho (2011) has conducted a review of theoretical models which relates to decision making in construction management literature. She points out that authors built on previous models in order to construct their own contributions. Another review made by Jato-Espino et al. (2014) find many different multi-criteria decision-making methods have been presented in scientific articles over the years.

Approaching decision-making processes by developing theoretical models or methods for how they should be done is an important topic, but what the studies are missing is to account for what is actually happening during decision making on construction projects. This present study investigates how decision-making processes occur during an energy renovation of existing buildings.

In recent years, some researchers have guided readers' attention towards why (or why not) sustainable measures are taken during the process of renovating single-family houses. Single-family housing accounts for a large part of the existing building stock in many countries in the EU. Incorporating sustainable measures when the houses are getting renovated might lead to reductions in carbon emissions on a national scale. Vlasova and Gram-Hanssen (2014) questioned in their study to what extent ideas of the future everyday life of inhabitants are included in the planning and design of retrofits of detached, owner-occupied houses. They highlight that decisions about implementing technologies which can reduce the energy consumption of the houses have impact on the social practices of the householders. They therefore suggest focus on how the material layouts of retrofitted buildings and the sustainable everyday practices of inhabitants relate to each other. Whereas the study by Vlasova and Gram-Hanssen is one example of an empirical study of renovation of single-family houses, only little attention has been paid on empirical studies of decision-making processes during energy renovation of multifamily buildings. Palm and Reindl (2016) on the other hand study how energy efficiency measures are taken during renovation of multifamily buildings. Their study investigates the renovation processes of one housing organization in Sweden where explicit goals of improved energy efficiency have been expressed, and their focus has been on how these goals have been made part of the planning and design phase. They highlight that only little attention has been paid to the planning and design of renovation projects in multi-unit dwellings, even though decisions taken in this phase has great impact on the building after renovation. Design processes during energy renovation of multilevel housing has been understudied, and especially negotiations leading up to the "final" renovation design.

In recent study by Buser and Carlsson (2017), decision-making processes during renovation of single-family houses are shown to be shaped by material features of the building presented in technical reports together with the social practices with which the house is associated. The material features and social practices might even limit the scope of the renovation projects in some situations. Their study shows how a sociomaterial approach can be important when studying decision-making processes, because householders' decision whether to renovate or not (or to what degree) can be influenced by legal documents and energy reports which display certain interests, positions or goals. The present paper extends this research interest and scrutinizes how decisions are negotiated during energy renovation of multifamily housing blocks from a sociomaterial approach. Similar to Yaneva (2008), I reconstruct decision-making processes from a 'renovation in the making' and how material features, as described by Buser and Carlsson, shifts interests, convince others of a statement and display certain interests and positions. The present paper draw on empirical material from field work conducted in relation to the renovation of a social housing estate in Denmark.

The role of objects in decision-making processes

Studying design of buildings are important, because designers can easier change the building represented in their drawings than the construction worker when construction already has begun. Changing materials of the walls or erasing rooms as a result of budget cuts can happen by a single click on the computer during design activities. On the contrary, during construction the change has a higher cost; materials need to be cancelled, already made constructions might be torn down, new expertise might have to be enrolled, and so on. Practitioners are therefore interested in preparing the building prior to construction as good as possible. But building design is not only the planning of material things, it is also the resolution of sometimes competing social interests (Gieryn, 2002). Deciding on how the building becomes "as good as possible" is an act of negotiations among the designers on the project. Planning for the stability of the constructions, the fire safety of the building, and similar concerns are one part of building design. Another is the negotiations of space disposition, functions and aesthetics, where eventual owners or occupants might be involved in these discussions. As Gieryn (2002) puts it: "The interests of powerful voices in the design process are etched into the artefact itself" (page 42). The interest of the designers in what the building 'is' or how it 'should be' is translated into programs and sketches as these discussions are going on. Building design is far from being a neutral playground for exchange of political interests. Instead, designers have to take into account competing social interests and choose whether to include one set of interests or exclude another set of interests. In order to meet a diverse set of interests, designers have to negotiate requirements, make compromises and incorporate these into drawings, documents and other project material. The "final" design will therefore be a product of the choices made during design of the building. However, the "final" design conceal the many possible design decisions and why some were made and others not. The very interests, politics and power negotiations which permeate building design are hidden. In this paper, I take a glimpse into the "machine room" of building design in order to investigate how negotiations of interests progress on a renovation project.

The role objects has been observed to be crucial in interactions among designers within the architectural, engineering and construction industry. Henderson (1999) points out that sketches and drawings are the basic components of communication among engineers and designers. Designers' words are built around the drawings and sketches. The drawings and sketches are important means for organizing the design-to-production process and serve as "social glue" between individual and groups of designers (*ibid.*). One empirical example described by Bendixen and Koch (2007) demonstrates how drawings are used to negotiate briefs of a 'building-to-be'. In their case, drawings are developed and used to support political purposes. The negotiations about the brief for the building project illustrate how the number of storeys in a building quickly could move between four and six without any drastic outcomes. Later in the design processes, these kinds of manoeuvre would probably lead to losses of substantial amount of detailed design work. Tryggestad, Georg and Hernes (2010) argue that projects are not the product of rational decision making, but projects are more likely to be controversial, subject to different interpretations, and something which needs to be negotiated among the parties involved. Project goals and design ambitions therefore change through the course of a construction project in various "trials of strengths" (Latour, 1987). In the case of Tryggestad, Georg and Hernes, objects such as artistic sketches, drawings, photos and models are not just considered as visualizations of knowledge (Whyte, 2003), but the objects actively mediate construction processes and transforming ambitions along the way. The work on these objects and the circulation of them is used to test the design's technical feasibility. Authors have for some time called for attention to the role of objects in construction projects (e.g. Bresnen and Harty, 2010). In this paper, I want to extend these studies of decision-making processes by highlighting the importance of how various objects are presented for the parties along the way and give an example from an energy renovation project.

My account of the decision-making processes from the case is based on actor-network theory and an interest in the mundane and material practices (Latour, 1986) of designing a renovation project. In this paper, I am interested in following how people presents arguments on paper, on prints and diagrams, as well as in physical objects that take up space in meetings. Similarly to how scientists are explaining the world from inscriptions (*ibid.*), I want to trace how engineers, architects and tenants are explaining their world through choices of which objects to work with and present for each other.

Empirical setting and research methods

Social housing estates are increasingly subject to renovation. In many places, the age of social housing estates has resulted in poor living conditions and poor energy performance, and the aim of the renovation projects is to modernise the buildings and improve their energy performance. This paper gives insights to a case study of one such renovation project in Denmark, namely the renovation of four multi-family apartment blocks which are rented out as social housing. The case study focusses on the design phase and how decisions on energy-efficient measures are made during this period. One of the overall goals with the renovation project is to reduce the energy consumption of the apartments from an estimated consumption of approximately 130 to 50 kWh per square meter per year. The case study explores how the involved stakeholders negotiate and decide on initiatives to reduce energy consumption. This paper focus on one particular issue how a mechanical ventilation system with heat recovery should be installed in the four buildings.

Mechanical ventilation with heat recovery is one mean to drastically reduce the heating demand of a building (Meijer et al., 2009). A ventilation system like this reuses the warmth from the indoor air to pre-heat the supply air from the outside. The idea is therefore that the heating system, in this case radiators, would not have to heat up the indoor air as much as if there were no heat recovery. Together with other initiatives for energy reduction (such as thicker insulation in the building envelope, as well as replacement of the existing windows, doors and heating systems with new and more efficient versions), the ventilation system can reduce energy consumption while also improving the indoor air quality. This paper describes the processes leading up to the decision regarding the type of ventilation system; paying particular attention to which role different objects play during the negotiations. The decision in focus is whether a centralized ventilation system or decentralized ventilation system should be installed in the buildings (both with heat recovery). The decision has implications on maintenance and use of the ventilation units, which I will elaborate on in the section 4.

Social housing estates are owned and managed by non-profit housing associations in Denmark. The rent in social housing is regulated by the Danish government in order to accommodate for tenants with low incomes. Each housing association has their estates organised into individual housing sections which are financially independent from each other. The housing association is responsible for the strategic management of the housing sections, while the housing sections are responsible for the everyday management of their (respective) estates. The social housing sector builds on a principle of democratic tenants' participation and self-governance. The tenants living in a housing section elect representatives to a board of tenants for that particular housing section. The board of tenants is responsible for the daily management and financial governance of the housing section. Tenants are entitled to exert influence on the agenda at the meetings in the board of tenants if they have any concerns or issues that they would like to raise. Once or twice a year, a general assembly is held in which all tenants in the housing section are welcome to participate. The board of tenants is in this case asked to decide which kind of mechanical ventilation they want in the apartments after renovation, and therefore play an important role in the discussions.

The case study revolves around a renovation project initiated by a housing association and supported by the particular housing section in which the buildings are located. The housing section, and in particular the board of tenants in this section, have been interested in renovating the estate since 2009-2010. Their interest stems mainly from a draughty building envelope, old water and heating systems, as well as problems with mould in some apartments. The renovation project went through different design proposal before it started officially in 2015. Most of the renovation costs are financed by the housing section themselves (by increasing the rent), but the project has also received economic support from the Danish National Building Fond. The role of the construction client is shared between the housing association and the housing section. The housing association manages the strategic decisions regarding estate operation in line with their overarching goals pertaining to all the housing sections, while the housing section, and especially the board of tenants, manages practical decisions about how building components and systems should be constructed to meet the wishes of the tenants. The housing association appoints a renovation committee which includes representatives from the housing association, the housing section and the consultancy companies allocated on the renovation project. The main purpose of the committee is to present details about the renovation project for the board of tenants, i.e. explain the technical, organizational and financial issues, so that the board can decide on specific issues. In this paper, I describe the process of one of these decisions.

The study is a qualitative field research based on interviews, observations, and a document study. The field work was conducted from August 2015 to January 2017 in which the renovation project moved from schematic design over detailed design to bidding procedure and tender. 22 meetings were observed, 12 interviews conducted and project material gathered along the way. Additionally, I visited the consultancy company which was responsible for detailed design of the project for 16 days over a two months period in order to follow discussions between project meetings. For the purpose of the study presented here, three interviews were conducted by the author; one interview with a ventilation engineer from the mentioned consultancy company which also is responsible for the design of the mechanical ventilation system, one interview with the project leader from the housing association, and one interview with three members from the board of tenants, one of them being the chairwoman of the board. The informants were asked about how they relate to the initiatives to reduce energy consumption taken in the renovation project and how decisions about the mechanical ventilation system were made. Sound was recorded during the interviews and the recordings were transcribed in order to get a sense of the informants' arguments. After transcription, the data was correlated with meeting minutes from the renovation committee meetings and field notes from observations at project meetings. The reconstruction of the decision processes presented in section 4 is made on basis of a triangulation between the interviews, the documents and my own observations. At observations of project meetings, I recorded sound and took notes. During the meetings, I focused on how the participants referred to entities either present in the room or of which had been circulated among them by for example email. During the field work, a conflict seemed to arise amongst the participants. An issue which led to discussions for four months. The discussions are what led me to write this paper.

Decision on mechanical ventilation

The case revolves around a decision whether to install decentralised or centralised mechanical ventilation system in four multilevel apartment buildings. The decision has implication on how the ventilation system will be used and maintained. If the decentralised system is selected, then the tenants can operate it from their apartments. If the centralised system is selected, then only the maintenance employees would be able to operate it. Because the decision affects the tenants, the housing association wanted the board of tenants to decide what they would prefer. The decentralised ventilation units are placed in the apartments and the tenants can adjust the temperature of supply air and the airflow in each apartment separately. The centralised system has ventilation units standing on the roof or in the basement, and when the maintenance employees change the temperature of the supply air, they change it for all apartments that share the same staircase. If the board of tenants decide on a decentralised ventilation system then they themselves need to take care of some maintenance, namely changing filters in the ventilation units once or twice a year. The rest of the maintenance will professionals take care of, such as if the units break down. If the board of tenants decide on a centralised system, then the maintenance employees are responsible for changing the filters of the ventilation units. The board of tenants therefore encounter this decision and in this section I will describe how the decision process unfolded during the course of the project.

Experiences before the renovation project

First, I will introduce three experiences which, as I will show later, have had impact on which system the board of tenants choose in the end. The experiences have been told by the informants after the decision was made and they had to reflect on the process. The first experience is one that is prevailing in the housing association. The experience was told by the project manager from the association and she related the experience to some previous renovation projects made by them. In other estates, the housing association had installed centralised ventilation, where tenants had blocked the ventilation outlets in the apartments, because they felt draught from the outlets. Since the system is measured to be balanced across all apartments in, for example, one staircase or one building, blocking will lead to higher airflows in the remaining apartments. The action taken by the tenants gave the association some extra work in order to 'correct' the 'wrong' behaviour. First, the association needed to gain access to the all the apartments by notifying the tenants weeks in advance. Then inspecting the apartments, telling the tenants not to block the outlets, and re-adjusting the ventilation units.

Another experience about ventilation systems for social housing was expressed by the ventilation engineer from one of the consultancy companies designing the renovation project. His responsibility is to plan and design the ventilation system on the renovation project. When reflecting on typical ventilation systems for social housing during an interview, he stated that he usually did not plan decentralised for multilevel apartment buildings. His experience is that manufacturers usually recommend centralised systems for multilevel apartment buildings and decentralised systems for detached, single-family houses.

A third experience about ventilation units in multilevel apartment buildings is expressed by the board of tenants. Their experience revolves around a centralised unit standing on the roof of a newly built multilevel apartment building next to their apartments. The building next to their apartments was constructed in 2012, and since then, tenants have heard noise from time to time coming from the unit. The unit "wails over there", as one member of the board states. The board assumes that the noise is due to lack of maintenance and changing the filters would help. The noise is reaching one tenant who live in the apartment block furthest away from the neighbouring apartment building. Additionally, the board do not like the appearance of the large metal boxes which comprise the units. This experience, together with the other two, has been expressed after the decision of ventilation system had been chosen.

In August 2015, a discussion on the renovation project starts about which kind of ventilation system to install in the buildings. The backdrop of the discussion is the three experiences described above. The discussion goes on for three months and involves three important events: 1) A presentation by the ventilation engineer about pros and cons for the two types of systems, 2) A visit to the Danish Technological Institute arranged by the housing association, and 3) the "final" decision made by the board of tenants.

Presentation by the ventilation engineer

At a meeting in September 2015, the ventilation engineer presented the two possible ventilation setups for the board of tenants and the rest of the renovation committee. His presentation consisted of the following themes: The two different ventilation principles, maintenance of the two systems, service life of the different units, variations in occupant influence, as well as estimated prices of instalment and replacement. Prior to the meeting, the engineer had send a written note about the ventilation options to the meeting participants. In the note, the engineer describes centralised ventilation as the "traditional" type of ventilation for these types of buildings and generally the note seems to favour the centralised version. The following section is taken from the introduction.

> *"Given that decentralised solution is an alternative to centralised ventilation solution – which not until recent years has become popular in the Danish housing stock – is the structure of the note built up by the differences between the decentralised solution in relation to the traditional centralised unit structure" (note written by the ventilation engineer, October 2015, translated by the author).*

The cost calculations stated in the document also favour the centralised version. The decentralised version is estimated to be almost six times more expensive if the tenants change the filters and almost ten times more expensive if the maintenance staff change the filters. Both compared to the centralised version. Additionally, the costs for replacing broken units in centralised version is estimated to be almost 33 percent lower than the costs for replacing decentralised units. The document ends by recommending the building client to choose a centralised system, because service of decentralised units would be a challenge. The engineer stated during an interview that he tried to convince the board of tenants to go with centralised system, but would plan and design which ever system they wanted. He distributed the note among the participants as an inscription device arguing for his interests and in hope of convincing the others. In the top of the note, it says that the purpose of the document is to be a "basis for decision", and based on my interviews, the document has been part of considerations in the board of tenants and the housing association.

The board of tenants did not get convinced about any of the two types of systems after reading the note and hearing the presentation from the engineer. Their reaction to the arguments was that it would not matter which system they choose.

> *"[The engineer] did not recommend any of the two systems. He told us it did not matter which one we chose. There would be practical and impractical things with both units" (member of the board of tenants, November 2016, translated by the author).*

Even though the engineer tried to convince the board of tenants, the tenants were not convinced and for them the decision was still open. They wanted more information about decentralised units, because they were displeased with the centralised units nearby their apartments, but they were not completely sure on the decentralised either. The next event is their effort to learn more about both ventilation principles, but especially the decentralised version.

Visit to the Danish Technological Institute

The members of the renovation committee took a field trip to the facilities of the Danish Technological Institute[10] (TI). Among them were the board of tenants, representatives from the housing association (e.g. the project manager), and representatives from the consultancy companies (e.g. the ventilation engineer). The visit consisted of two parts; first, a presentation by two of their scientists which both are trained engineers, and second, a visit to their laboratory to see examples of decentralised ventilation units. The project manager from the housing association recall the main points of the visit in the following way.

> *"A researcher told us about the two types of ventilation – benefits, disadvantages, experiences, what people do today, and so on. There was brought a couple of decentralised units in, so you could see them physically. You could see how it was to take such a filter in and out of the unit." (project manager from the housing association, November 2015, translated by the author).*

The way the participants remember the presentation by the scientists was similar to the one that the ventilation engineer had given earlier. Again they understood that they could choose both kinds of systems, but the information about prices was different this time.

> *"We were not recommended the one over the other. Price-wise it was the same." (another member of the board of tenants, November 2016, translated by the author).*

The presentation by the scientists act as an anti-program (Latour, 1990) against the interests of the ventilation engineer. The argument put forth by the ventilation engineer was that there would be a price difference, but the scientists stated no difference in price.

After the presentation held by the scientists, all the participants went into the laboratory of the Technological Institute. In the laboratory, two decentralised units were placed so the participants would be able to see them "physically", as the project manager called it.

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[10] The Danish Technological Institute is a consultancy company specialised in developing and testing technologies, e.g. energy and climate, food, biotechnology, materials, production and construction technologies. For more information, see http://www.dti.dk/about.

The ventilation engineer said that the display was to show "how the box looks like and how you open and close it."

The reaction from the members in the board of tenants was that the visit was quite satisfying for them. Seeing the physical ventilation units seemed to make quite a difference. The chairwoman in the board describes it in the following way.

> *"We got the experts from [TI], who have studied many things, to present a review of ventilation systems we could have in the apartments. That is, like a fridge. Mechanical ventilation. We saw different things. How much space it took up, what it was able to do, and so on. It was a real eye-opener" (chairwoman of the board of tenants, November 2016, translated by the author).*

The board of tenants was told how to change the filters in the units, they heard them run silently (like "a fridge"), and saw how much room they took up. The chairwoman of the board calls it "a real eye-opener", because until the laboratory visit, they had only been talking about the ventilation system as technical values, economic values, as well as lines on plan drawings and photos of similar units. After the visit, the board of tenants had a better sense of how the ventilation units could be able to fit in their future apartments.

Decision on which type of ventilation system it should be

The two types of ventilation systems both have benefits and shortcomings. The ventilation engineer presented his point of view and recommended centralised units. The scientists from the Technological Institute presented their point of view, plus physical examples of decentralised units. The board of tenants ended up choosing decentralised ventilation units for the project. The adjustable airflow and temperature on supply air into the apartments were important issues for the board of tenants. As a member of the board of tenants explains it:

> *"We decided on the decentralised units, because then people can choose their temperatures themselves. You can adjust the supply air from 19 to 22 degrees, if I remember correctly" (member of the board of tenants, January 2017, translated by the author).*

As an earlier quote from a member of the board of tenants stated, the scientists from the Technological Institute presented the two types of ventilation systems without a price difference. Next to this, the board of tenants were displeased with the centralised unit on the neighbouring building. Also the minor sound the decentralised units were making pleased the board. The board of tenants had these issues in mind, but their certainty became first apparent after the visit at the TI. As one tenant describes it:

> *"We should figure out how it could be placed in the apartment, where it should be placed, because there were different kinds [of decentralised units]" (member of the board of tenants, January 2017, translated by the author).*

By the quote above, it seems that seeing the physical units had an impact on th board of tenants' decision.

Discussion

The present study reports on a renovation project "in the making" (Yaneva, 2008) when design decisions are open to interpretation, fluid and valuated in many different ways. The complexity of renovation projects are extensive, and this study is only a fracture or a small peep into the "machine room" of designing. Following decision-making processes, the difficulties the participants meet, the unpredictable obstacles turning up, the opposition the participants are meeting, is a very difficult task. I have tried to reconstruct how a particular decision unfolded over the course of four months, but by taking the complexity of renovation projects into mind, then this particular decision process could have turned out in several other ways. The interesting part is how social structures are "becoming" through design (Gieryn, 2002). The way this decision process has been, the future tenants of the estate need to change filters in their ventilation units. They are handed over maintenance tasks. The question then becomes if they "subscribe" to this idea of themselves which originated from the designers' intentions (Akrich and Latour, 1992).

A lot of work has been done on drawings (e.g. Henderson, 1999; Bendixen and Koch, 2007; Whyte, 2007), but less attention has been paid to all the other types of objects that constitutes construction processes. In this case, a document, presentations by professionals and two ventilation units were also part of decision-making processes. Since there is not many other studies to compare these observations with, the role of these objects are still up for question. It seems from this case that the physical ventilation units had an impact on the decisions made by the board of tenants, but if this will be the case in other similar projects must be an empirical question.

The advices made by experts such as the ventilation engineer and the two scientists at the Technological Institute also seemed to play a part in the decision. However, as pointed out by Buser and Carlsson (2017), different sources of expertise might provide contradictory advices. In this case, the presentation from the ventilation engineer was slightly out of sync with the presentation by the scientist, while the latter disagreed with the price difference presented by the first. Expert knowledge, like the decision processes, is therefore not to be regarded as "black boxes" (Latour, 1987), but can play out many different ways.

Conclusions

The present study highlights the importance of studying energy renovations 'in the making' and reports on a particular decision-making process by focussing on which role objects play in the negotiations among the participants. Based on a qualitative field study consisting of interviews, observations, and document study, the study reconstruct three main events in which participants discussed whether to install centralised or decentralised ventilation in the renovated buildings and where objects played an important role. The three events were a presentation by a ventilation engineer which favoured centralised ventilation, a visit to the Danish Technological Institute which seemed to favour decentralised ventilation, and the choice made by the board of tenants which landed on decentralised ventilation. Two types of objects were observed to have an impact on the discussions, which were a note written by the ventilation engineer and physical decentralised ventilation units presented by the Technological Institute. Studies of objects' role in decision-making processes during construction projects is scarce, however this approach to decision making in construction could lead to a reassessment of how we understand 'actual' decision-making processes.

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Energy renovations are crucial means to reduce energy consumption from the existing building stock. However, research does not widely attend to the practical details of designing for energy savings. Much research focuses on the technical and economic aspects of energy renovations. However, energy performance as a design problem remains overlooked or taken for granted in most of the existing literature. This study draws on the sociology of asssociations and investigates how designers make energy-saving design features knowable and actionable through their everyday design practices. The analysis shows how energy-saving features emerge from negotiations of interests and the interactions between designers and material objects. The study highlights processes of persuasion, learning and stabilisation/destabilisation in the making of energy renovations. Based on the findings, this study suggests that if research does not draw attention to the everyday challenges and conflicts happening during the design of energy renovations, then ambitions concerning minimum energy consumption in buildings are likely to fall short.

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