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Integrating operational knowledge in design of new buildings to improve facility performance - A comparative study of building and large ship projects

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Integrating operational knowledge in design of new buildings to improve facility performance

-A comparative study of building and large ship projects

Helle Lohmann Rasmussen

PhD Thesis
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DTU Management
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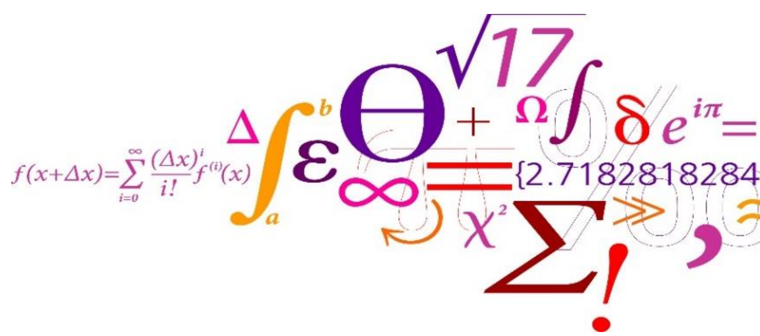

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Summary

Some new buildings do not live up to expectations when put into operation. For example, research has revealed a gap between expected and actual energy consumption. Other important parameters, such as indoor climate, maintainability or functionality, can also be disappointing in new buildings. This has negative consequences for the activities intended within such buildings, for their occupants' quality of life, for the cost of operation and for their environmental impact.

Both researchers and practitioners have found that difficulties can be reduced if building clients ensure that the future operations of buildings have already been considered in the design process of new projects. This requires that knowledge obtained from buildings already in operation be transferred to the design process of new buildings. A number of tools and methods have been developed to achieve this: some include the direct involvement of experts in building operations, while others are not based on such direct involvement but on codified knowledge instead. The underlying assumption of previous research has been that the more knowledge that can be transferred – e.g. by involving operational staff or using other tools or methods to transfer knowledge from operation to design – the more future operations will be taken into account during design, resulting in enhanced facility performance.

The ambition to integrate operational knowledge into design is not unique to building projects. It is also relevant in the design of large ships. Here, negative consequences also occur if operations are not considered from the beginning. Therefore, this study compares how operational knowledge is integrated into the design of buildings and large ships. This approach aims, on the one hand, to see whether there are tools and methods that can be shared, and on the other, to see what new knowledge this comparison reveals about integrating operational knowledge into design.

Thus, the overarching purpose of this study is to investigate **how operational knowledge is integrated into the design process of buildings in comparison to that of large ships, aiming to improve facility performance.**

As a second approach, the phenomenon of knowledge transfer from operation to design is studied through the lens of theories on knowledge transfer from knowledge management research. Here, two perspectives on knowledge transfer are dominant: the technocratic and the behavioural approaches. The technocratic approach recommends that knowledge be codified and stored in order to be applied in a new context, whereas the behavioural approach focuses on the 'people side', stressing that much knowledge is tacit and can only be transferred through interaction.

This thesis is paper-based and consists of six published research papers in addition to a synopsis. The papers rely primarily on qualitative methods, including a single case study, expert interviews, workshops and focus group interviews as well as a multiple case study on how operational knowledge is integrated into the design processes of buildings (2) and ferries (3), respectively. Additionally, one paper is based on a questionnaire survey.

As a starting point, the study focuses on building projects. Here, the research shows that a large number of tools and methods to transfer knowledge from operations into the design process have already been developed, described and implemented in practise. Moreover, the findings indicate that operational staff is, to a large extent, involved in the design process of the investigated building cases. Three main

parties within the building client were found to be responsible for the successful transfer of knowledge from operation to design: the top management, the building client division and the operations division.

Moreover, this study shows that facilities managers are not only concerned about the performance parameters, such as energy consumption or operation and maintenance, of their new buildings. Two of the research papers included in this thesis describe the diverse difficulties related to the operation of new buildings. A typology of 12 performance gap types in new buildings, as seen from a facilities manager's perspective, is developed.

Additionally, the thesis identifies 35 specific difficulties that facilities managers in new buildings experience. Based on the responses to a web-based questionnaire conducted with facilities managers of new buildings in Denmark, the difficulties are ranked from 'most often experienced' to 'least often experienced'. The difficulties most often experienced concern digital material from building projects. Other high-ranked difficulties include unexpectedly high energy consumption due to the lack of commissioning of technical installations and difficulties with indoor thermal climate.

In view of the identified performance gaps, in many projects, it is insufficient for project managers of new building projects to limit their focus to, for example, energy consumption and operation and maintenance. A project manager needs to consider the purpose of the building in a broader sense and must balance many types of performance. In the cases examined, where project managers had a strong focus on operations, less attention was paid to, for example, user experience and aesthetics, and less focus was placed on managing a large project. This means that if, for example, user experience and aesthetics are important in order for a building or a ship to meet its purpose, then the solution does not appear to lie in appointing a project manager with a strong focus on operations.

The multiple case study brought to light a correlation between on one side the number of tools and methods used to ensure the integration of operational knowledge into design and on the other side the affiliation and focus of the building client's project manager. Perhaps, in contrast to what one might think, *fewer* tools and methods were used in those cases in which project managers had a *stronger* connection to operation and a long-term interest in the new building or ship, while *many* tools and methods were used in those cases in which project managers' connection to the operations was *weaker*. However, nothing suggested that operations were less taken into account in the cases where the least tools or methods were used – the opposite actually seemed to be the case. One possible explanation for this is that when operations are a matter of concern to the project manager, he or she ensures that operations are taken into consideration with limited use of tools and methods. Additionally, in some cases, project managers had prior experience in operation; thus, it was presumably redundant to transfer knowledge – since it was already there.

In those cases in which project managers did not have a strong connection to operations, the study showed that extensive resources went into transferring knowledge about operations into the design process. Unfortunately, design processes are rather complex today, and the literature even describes an 'information overload' in projects, thus indicating a risk that some knowledge might never reach a project manager's attention, for instance, and be consequently wasted. This study includes examples in which the requirements outlined in detailed design guidelines were not incorporated into the projects. Hence, this thesis, like certain parts of the body of knowledge management literature, points out that the question a building client needs to ask him or herself is not how more knowledge can be transferred to the design process but rather how various project actors pick up knowledge and integrate it into, for instance, the design or decision proposals.

Therefore, how individuals are motivated to seek out and integrate knowledge about operations into the design processes they participate in is one of the questions that future research and practice must answer. Furthermore, it is also necessary to discover how the knowledge that they need can be made accessible at the relevant time and place in order to limit knowledge waste resulting from 'information overload' in projects. Moreover, how key actors, such as project managers, balance numerous performance parameters whose hierarchy of relative importance is contingent on a project's purpose.

This PhD project has been supported by the Danish Maritime Fund through the Copenhagen School of Marine Engineering and Technology Management, Sweco A/S, Center for Facilities Management – Realdania Research (CFM) and DTU.

Resumé (Danish)

Nogle nye bygninger lever ikke op til forventningerne, når de sættes i drift. Forskning har påvist et gab mellem det forventede og faktiske energiforbrug, men også andre væsentlige parametre kan skuffe i nye byggerier, f.eks. indeklima, vedligeholdelsesvenlighed eller funktionalitet. Det har negative konsekvenser for det, der skal foregå i en bygning, for livskvaliteten af dem, der skal være i bygningen og for driftsudgifterne, ligesom det øger bygningens negative miljøpåvirkninger.

Forskere såvel som praktikere har fundet frem til, at vanskelighederne kan reduceres, hvis bygherren sørger for at den fremtidige drift tænkes ind allerede under designprocessen af et nyt projekt. For at kunne det, skal viden fra bygninger, der allerede er i drift, overføres til designprocessen af nye bygninger. Der er udviklet en række redskaber og metoder, der kan hjælpe med det. Nogle redskaber og metoder består i at involvere personer, der har erfaring med bygningsdrift, mens andre redskaber ikke er baseret på direkte involvering, men i stedet på formalisering (kodificering) af viden. Udgangspunktet for tidligere forskning har været at desto mere viden vi kan overføre, f.eks. ved mere involvering af driftspersonale og mere brug af andre redskaber til at overføre viden fra drift til designfasen, desto mere vil den fremtidige drift blive taget i betragtning under byggeriet.

Ambitionen om at indtænke drift i design er ikke unik for bygningsprojekter. Det er også aktuelt i design af store skibe. Her har det også negative konsekvenser, hvis driftsfasen ikke tænkes ind fra starten. Derfor sammenligner dette studie, hvordan driftsviden integreres i design af bygninger og skibe. Formålet med dette greb, er dels at se om der er nogle konkrete redskaber der kan deles, og dels for at se hvad sammenligningen bringer af ny viden om det at overføre viden fra drift til design.

Det overordnede formål med dette studie er således at undersøge **hvordan viden om drift integreres i design processer af nye bygninger sammenligning med store skibe, med henblik på at øge performance af den nye facilitet.**

Ligeledes inddrager studiet litteratur om viden overførsel fra forskningen i videns ledelse *('knowledge management')*. Her er to tilgange til vidensoverførsel dominerende: Den teknokratiske og den adfærdsmæssige tilgang (min oversættelse). Den teknokratiske lægger vægt på at viden formaliseres (kodificeres) og opbevares for at bliver anvendt i en anden kontekst. Den adfærdsmæssige tilgang fokuserer på 'person-delen' og understreger at meget viden er 'tavs', personafhængig og ikke kan flyttes uden interaktion.

Afhandlingen er artikelbaseret og består foruden en sammenfattende synopsis, af 6 publicerede forskningsartikler. Artiklerne er baseret primært på kvalitative metoder, herunder et single-case study, ekspert interviews, workshops, fokus gruppe interviews samt et multi-case studie af hvordan driftsviden integreres i design processer af hhv. bygninger (2) og færger (3). Yderligere er et paper baseret på en spørgeskemaundersøgelse.

Den første del af undersøgelsen fokuserer på bygningsprojekter. Her påviser undersøgelsen, at et stort antal værktøjer og metoder til overføre viden fra drift til design allerede er udviklet, beskrevet og implementeret i praksis. Resultaterne viser endvidere, at driftspersonale i vid udstrækning er involveret i designprocessen for de undersøgte byggesager. Tre hovedparter inden for bygherren er ansvarlige for en vellykket overførsel af viden fra drift til design: den øverste ledelse, bygherreafdeling og driftsafdelingen.

Dernæst viser undersøgelsen, at facilities managers ikke kun er bekymrede for performanceparametre, såsom energiforbrug eller drift og vedligeholdelse af deres nye bygninger. To af forskningsartiklerne, der er inkluderet i denne afhandling, beskriver de forskellige vanskeligheder forbundet med driften af nye bygninger. En typologi af 12 typer af performance gab i nye bygninger set ud fra en facilities managers perspektiv er udviklet som en del af undersøgelsen.

Desuden identificerer afhandlingen 35 specifikke vanskeligheder, som facilities managers i nye bygninger oplever. Baseret på en web-baseret spørgeskemaundersøgelse, hvor danske facilities managers har svaret, rangeres vanskelighederne fra 'oftest oplevede' til 'mindst ofte oplevede'. De vanskeligheder, der ofte opleves, vedrører digitalt materiale fra byggeprojekter. Andre højt rangerede vanskeligheder inkluderer uventet højt energiforbrug på grund af manglende koordineret idriftsættelse af tekniske installationer og vanskeligheder med termisk indeklima.

Set i lyset af forskellige typer af performance gab er det i mange projekter utilstrækkeligt, at projektlederen fokuserer på f.eks. energiforbrug og drift og vedligehold. Det er ofte nødvendigt at tænke formålet med bygningen i bredere forstand, og projektlederen skal balancere mange typer af performance. I de cases, der er undersøgt i denne afhandling, hvor projektlederen havde stor fokus på drift, var der mindre fokus på f.eks. brugeroplevelse og æstetik, samt mindre fokus på det at lede et stort projekt. Det betyder, at hvis f.eks. brugeroplevelse og æstetik er vigtige for at bygningen eller skibet kan tilgodese sit formål, så ser det altså ikke ud til at løsningen er at udpege en projektleder med stort fokus på drift.

Case studierne viste, at der er en sammenhæng mellem på den ene siden hvor mange redskaber og metoder, der bruges til at sikre integration af driftsviden i design, og på den anden side tilhørsforhold og fokus hos bygherrens projektleder. Muligvis modsat af hvad man skulle tro, så bruges der færrest redskaber og metoder, hvis projektlederen har en stærk tilknytning til driften og en langsigtet interesse i den nye bygning eller det nye skib, mens der bruges flest redskaber og metoder, hvis tilknytningen til driften er svagere. Der er dog ikke noget, der tyder på at de faciliteter, hvor der bruges færrest redskaber, har et mindre fokus på drift; snarere tværtimod. Hvordan kan det være? En mulig forklaring er, at når projektlederen har en indbygget interesse for drift, så sørger vedkommende for at drift situationen indtænkes med brug af få redskaber og metoder. Derudover har vedkommende i nogle tilfælde selv driftsviden. I så fald kan man ikke tale om at skulle overføre viden, da den allerede er der, og det overflødiggør selvsagt redskaber og metoder.

I de cases, hvor projektlederen *ikke* havde stor tilknytning til drift, viste undersøgelsen, at der blev brugt omfattende ressourcer på at overføre viden om drift til designfasen. Desværre er designprocesser i dag allerede rigeligt komplekse, og man taler ligefrem om 'information overload' i projekter med indikation af, at noget viden altså vil blive 'spildt'. Det er der også eksempler på i undersøgelsen, f.eks. at krav i detaljerede bygherrestandarder ikke blev indarbejdet i projekterne. Dermed peger afhandlingen, i lighed med dele af litteraturen om videns ledelse, på at det snarere handler om, hvordan viden *integreres*, end hvordan den *overføres* Det ændrer fokus fra mængden af viden, der flyttes rundt i organisationen, til de aktører, der skal samle viden op og integrere den i f.eks. designforslag eller beslutningsoplæg.

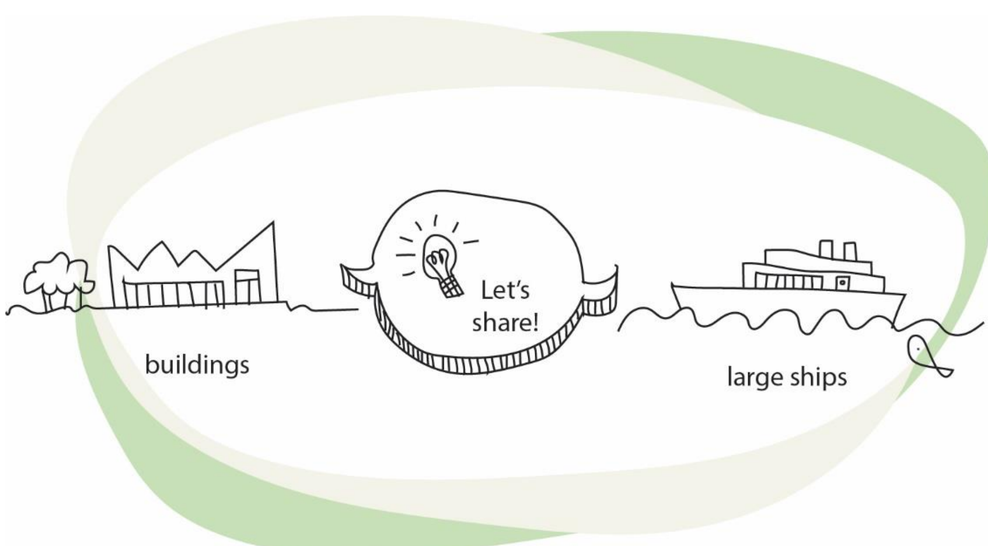
Blandt de spørgsmål, som fremtidig forskning og praksis må besvare, er derfor, hvordan individer motiveres til at opsamle og integrere viden om drift i de designprocesser, de deltager i, samt hvordan de får adgang til den viden på det tidspunkt, hvor de har brug for det, uden at viden spildes pga. 'information overload' i projekterne. Derudover, hvordan centrale aktører, f.eks. projektledere, balancerer de mange performance parametre, hvis indbyrdes hierarki af vigtighed er betinget af projektets formål.

Ph.d. projektet er støttet af Den Danske Maritime Fond via Maskinmesterskolen København, Sweco A/S, Centre for Facilities Management – Realdania Forskning (CFM), samt DTU.

Preface

When I began my PhD studies in December 2016, I already had more than 10 years of experience as a building project architect and manager, primarily within the area of technical facilities' refurbishment. My PhD work is undoubtedly influenced by my experience as is my motivation for completing this PhD project. From my personal experience, I know that - despite my former organisation's high ambitions to integrate operational knowledge into new building projects - new buildings could often be more operation-friendly. Moreover, it was obvious that the levels of frustration and conflict during the projects were high when colleagues from the building client department involved the colleagues from the operation department. Consequently, precisely to investigate that phenomenon, I quit my job as a project manager within the Facilities Management (FM) department and changed from being affiliated with the support business to the core business of the Technical University of Denmark (DTU).

Prior to beginning my PhD study, as well as throughout it, I repeatedly heard operational staff-whom I either interviewed or observed say that '*designers don't listen, they do as they please, regardless of what we say*'. Conversely, design team members and project managers say that the operational staff are too demanding or as one interviewee commented by saying that '*they would ask for golden taps if they could*'. This is found in both types of projects under investigation-that of buildings and large ships-and demonstrates that, despite evidence of the value of operational knowledge in design, the process is not without tension.



External funding and 'advisory board'

The funding from DTU was supplemented by four external parties: one of which are primarily interested in ships, one interested in both ships and buildings, while the other two are primarily interested in buildings. This external funding came from:

1: The Danish Maritime Fund, which is a commercial foundation with the objective to support activities 'that grow and develop the Danish shipping and shipbuilding industries' (https://www.dendanskemaritimefond.dk/english/).

2: The Copenhagen School of Marine Engineering and Technology Management, which offers a bachelor's degree programme in Marine Engineering. In Denmark, marine engineers work in both the shipping industry as well as various land companies, of which many are in the FM field (https://www.msk.dk/copenhagen-school-of-marine-engineering-and-technology-management). The school of Marine Engineering administered the funding from The Maritime Fund. Consequently, the school represented both their own and the fund's interests in the project.

3: Sweco A/S, which is an international engineering and architect consultancy company. Funding came specifically from the Department of Facilities Management at Sweco A/S, which also participated in the project as a 'stakeholder'. The services provided by the Department of Facilities Management include management of properties, coordination and optimisation of operation and maintenance as well as services (https://www.sweco.dk/en/our-offer/management-services/?service=Facilities+and+Asset+Management).

4: Centre for Facilities Management – Realdania Research, which was an externally funded research centre at DTU at the time, with the aim to strengthen research within FM (http://www.cfm.dtu.dk/english/about_cfm).

The contact persons from these funding organisations, with the exception of the Danish Maritime Fund- which was represented by The Copenhagen School of Marine Engineering and Technology Management- acted as an 'advisory board'. I held six meetings with this board, where I presented the preliminary findings and asked for their comments, reflections and suggestions in terms of alternative interpretation of findings. The purpose of these meetings was to further inform and validate the findings and they were mostly conducted as a combination of presentations, discussions and workshops. Furthermore, at these meetings, I outlined the work to come and asked for suggestions related to interview subjects, relevant cases, etc.

Acknowledgements

This thesis completes three years of PhD work and what an amazing three years it has been! I am certain that the fact that I immensely enjoyed becoming a researcher was obvious to everyone around me, including my family and friends. From the very beginning, being a PhD student has been the best job that I ever had and, to the very end, I enjoyed every single day. While the work was often challenging and involved endless hours, it was nevertheless meaningful and inspiring more than anything else. I am forever grateful for the great efforts that Susanne Balslev Nielsen put into raising the necessary funding and into formulating a PhD project that I could apply for. I am even more grateful that she, together with Per Anker Jensen, believed that I was the right candidate.

First, I would like to express great appreciation to my supervisor Per Anker Jensen. You offered your advice and time to me in such a generous manner, including more than 50 supervision meetings (I know because I have the minutes of each of them) and uncountable 'open door' meetings. Your supervision strongly empowered me to follow my own research path. I would also like to thank my co-supervisor, Jay Sterling Gregg, for the support and inspiring philosophical conversations. I am grateful to both of you for your numerous reviews of many individual papers.

The interest that many people from both the academia and practice have shown in my study has been overwhelming. I am amazed by how open and willing the faculty staff and PhD students have been to take the time to discuss my research with me. This includes researchers at DTU, CBS, AAU Copenhagen and AHO Oslo as well as NTNU Trondheim, where Geir Karsten Hansen, Carmel Lindkvist and Dave Collins welcomed me as part of my external stay. Your insights, advice and critical questions have been priceless. Thank you!

I have equally appreciated the many discussions I have had with various practitioners about my research. You, too, took the time to discuss my research with me, which I highly appreciate. You helped me find the relevance of my study for practice while also making me realise that I was not going to find a quick-fix solution to your struggles with integrating operational knowledge into design. I apologise if that was the impression I gave you in the beginning.

Some people went far beyond discussing my work with me occasionally. Susanne Balslev Nielsen, Giulia Nardelli, Supuck Prugsiganont and Esmir Maslesa - you discussed my research and the process of 'becoming a researcher' with me for many hours and offered both professional and 'moral' support whenever it was needed. Thank you.

Many thanks is due to those of you from the funding partners who acted as my 'advisory board'. Thanks to Tanja Henriques Schou, Ole Teisen, Svend Åge Carlsen, Teis Tristan Nielsen, Arne Jakobsen, Tommy Birkebæk and Lisa Froholdt for your engagement and participation in my project. I left every meeting strongly empowered and inspired to move forward. I also thank to Department for Facilities Management at Sweco A/S for opening their office to me and for hosting me for a full three-month period and every Monday in the following period. I gained great insight from my 'Swecollegues'.

Furthermore, I would like to thank the Danish Maritime Fund - the biggest funding contributor - for the flexibility you showed when I realised that the initial idea of comparing ships, buildings *and* oil rigs was going to be incompatible with the three-year timeframe of my PhD. Thank you for approving the exclusion of oil rigs.

I am also grateful to Magnus Gary and Hans Otto Holmegaard Kristensen for generously sharing their extensive maritime network with me. You pointed me to relevant people and cases and opened many doors for me by saying the magic words 'say hello from me'.

Finally, I want to thank all of you who participated as part of my research data collection process. I am overwhelmed by your willingness to be interviewed, to share documents, to participate in workshops, validation meetings and so forth. I cannot mention you here by name-since some of you wish to stay anonymous or the cases you represent are anonymous-but please know that I am grateful to each and every single one of you.

To all of my friends and family, especially Mogens, who supported me when I quit my well paid and stable job to pursue the dream of completing this PhD - thank you! I am especially thankful for the efforts made so that I could leave Denmark to participate in conferences and seminars abroad and make repeated visits to NTNU, Trondheim. Thank you Gustav, Johanne, Thea and Nanna for letting me ease my feelings of guilt by bringing you back tons of sweets.

List of papers A–F, including my contribution to the papers

This thesis includes and is based on six papers, listed below. In addition to the included papers, I disseminated the research project into additional papers, including more 'popular' articles, and into presentations. Both a list of other publications and a list of presentations are included as appendices.

Paper A
Rasmussen, H. L., Jensen P. A., Nielsen S. B. and Kristiansen A. H. (2019) 'Initiatives to integrate operational knowledge in design: A building client perspective', *Facilities*, 37(11/12), pp. 799–812. DOI: 10.1108/f-02-2017-0021

I wrote the main parts of this published journal paper and collected and analysed a large part of its data. The last author collected data on the swimming facilities as part of his master's thesis.

Paper B
Jensen, P. A., Rasmussen, H. L. and Chatzilazarou, S. (2019) 'Knowledge transfer between building operation and building projects', *Journal of Facilities Management*, 17(2), pp. 208–219. DOI: 10.1108/jfm-05-2018-0030

I wrote a portion of this published journal paper - in particular, I contributed with part of the literature review and participated in the interpretation of findings. The third author collected data as part of her master's thesis.

Paper C
Rasmussen H. L. and Jensen P. A. (2020) 'A facilities manager's typology of performance gaps in new buildings', *Journal of Facilities Management, 18(1), pp. 71*-87. DOI 10.1108/JFM-06-2019-0024

I initiated and wrote the main part of this journal paper. I conducted data collection and analysis.

Paper D

Rasmussen, H. L. and Due, P. H. (2019) 'The legacy from construction projects to facilities management in Denmark: The good, the bad and the ugly', in *Proceedings of EFMC* in Dublin, Ireland, June 2019, pp. 168-177.

I initiated and wrote the main part of this conference paper and conducted the majority of the data collection as well as the entire analysis.

Paper E
Rasmussen, H. L. and Jensen P. A. (2018) 'Tools and methods to establish a feed-forward loop from operation to design of large ships and buildings', in *Proceedings of EFMC* in Sofia, Bulgaria, June 2018.

I initiated and wrote the main part of this published conference paper. I conducted data collection and analysis.

Paper F
Rasmussen, H. L. (2020) 'The challenge of integrating operational knowledge in building and ship design', accepted for publication in *Facilities*.

I am the sole author of this journal paper, which is accepted for publication. I did all data collection, analysis, literature review and writing.

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List of abbreviations

BIM	Building Information Modelling
BMS	Building management System
Capex/opex	Capital expenditure (project costs)/ operational expenditure
CBS	Copenhagen Business School
DTU	Technical University of Denmark
FM	Facilities management
HVAC	Heating, ventilation, Air condition and Control
LCC	Life-cycle costing
NTNU	Norwegian University of Science and Technology
O&M	Operation and maintenance
RQ	Research question
SECI	The model of Socialisation, Externalisation, Combination and Internalisation (Nonaka *et al*., 2000)
AAU	Aalborg University

1. Introduction

1.1 Motivation and background

A large number of new buildings does not live up to expected performance when they are actually used (Due and Stephensen, 2012; Hansen and Damgaard, 2012; Borgstein *et al.*, 2018; Lindkvist, 2018; Mallory-Hill and Gorgolewski, 2018). The literature describes a gap between the calculated and actual energy performance, labelled the performance gap (Wilde, 2014; Ornetzeder *et al.*, 2016; van Dronkelaar *et al.*, 2016; Gram-Hanssen and Georg, 2018; Mallory-Hill and Gorgolewski, 2018). Other aspects of building performance, such as functionality, indoor climate and operation and maintenance, have also been recognised to be deficient (Damgaard and Erichsen, 2009; Mohammed and Hassanain, 2010; Hansen and Damgaard, 2012; Hassanain *et al*., 2014; Frei *et al.*, 2017; Lindkvist, 2018). These deficiencies have a negative impact on the environment, economy, productivity and life quality of those who occupy buildings, including those who manage and operate them - the facilities managers. Thus, bridging the gap is certainly relevant and important.

Building projects have linear processes of realisation: design, construction and operation. Decisions and actions made at one stage impact the following stages. Previous research has pointed out that the design stage is especially crucial to the performance of completed buildings (Arditi and Nawakorawit, 1999; Le and Brønn, 2007; Loosemore and Chandra, 2012; De Silva *et al.*, 2018; Khalid *et al.*, 2019). Moreover, researchers have emphasised the design stage as important due to the fact that cost of changes in the early stages of a project is low, whereas changes in later stages are costly (Kolltveit and Grønhaug, 2004). Once a facility is in operation, changes can be expensive or even impossible to complete. Hence, some deficiencies are likely to be permanent once a building is in operation. Therefore, what clients who build to occupy must especially ensure is that those who design their new buildings consider operation from the very beginning of the process in order to get these buildings 'right' from the start.

To ensure that operation is taken into consideration in the design process, researchers have stated that knowledge needs to be transferred from operation to the design of new buildings (Le and Brønn, 2007; Mohammed and Hassanain, 2010; Jensen, 2012; Adeyemi *et al.*, 2019). This research has followed two trajectories, often in combination. In one, the tools and methods to transfer knowledge from operation to design were investigated, some of which include direct involvement of facilities management staff, often operational staff. In the other, the barriers to implementing these tools and methods, as well as the difficulties in involving operational staff, were investigated (Jauntzen, 2001; Hansen *et al*., 2010). This led to suggestions on how to overcome barriers and implement more tools and methods in order to transfer knowledge from operation to design. The underlying assumption has been that the *more* knowledge is transferred and the more facilities managers are directly involved, the *more* building performance will increase. However, this assumption is challenged by the notion of information overload in building projects (Kreiner, 2005; Winch, 2010; Jensen, 2012). Moreover, previous findings show that operational considerations do not always have the highest priority in a project team's challenge (Elmualim *et al*., 2009), regardless of the transfer of knowledge from operation to design.

The benefits of integrating operational knowledge into design to improve facility in operation does not apply to building projects alone. Knowledge about operation is also beneficial in new large ship projects (Gernez, 2019a; Tsujimoto and Orihara, 2019). New ship and new building projects have similarities

(Knotten *et al.*, 2016) that make it possible to compare them. Like buildings, ships are large and complex physical structures produced in projects in which their design, construction and operation are separated (Mallam *et al.*, 2015; Knotten *et al.*, 2016; Osterman *et al.*, 2016). Like buildings - and unlike other transportation types such as cars and trains – ships are developed as unique projects, where prototyping is not an issue (Andrews, 2012). Moreover, the operational expenditure (opex) throughout both a ship's and a building's lifetime exceeds the capital expenditure (capex). In addition, researchers have argued that designers have little experience with how their designs function in real life, both in terms of buildings (Fatayer *et al.*, 2019) and ships (Mallam *et al*., 2015). Yet, no prior research has compared the integration of operational knowledge in the respective design processes of buildings and ships. Comparing the two has the potential to identify the tools and methods that they can adopt from one another. Moreover, it provides the opportunity to gain understanding on how operational knowledge is transferred in different types of projects.

In the remainder of this chapter, I first present the research aim and research questions. Then, I briefly define the key concepts included in the aim and questions. Moreover, I account for the delimitations of the study. More detailed explanations and discussions of some of the terms and concepts are included in the theoretical background. Finally, I outline the structure of the thesis.

1.2 Research questions

Based on the assumption that the performance gap of new buildings will be minimized if knowledge from operation is successfully integrated in to the design processes of new building projects, this research aims to advance the understanding of how knowledge is transferred from the operation stage to the design stage in different types of projects. Two approaches shaped the research: Looking at the topic through the lens of knowledge management, in particularly knowledge transfer, and comparing how integration of operational knowledge is integrated in projects of buildings with projects of large ships. My research is guided by a main research question (MRQ) as follows:

MRQ: How is operational knowledge integrated into the design process of buildings in comparison to that of large ships, with the aim of improving facility performance?

To guide my investigation further, I formulated three supporting research questions (RQ) as follows:

RQ 1: Which tools and methods enable the transfer of knowledge from operations to the design process of building projects? Further, what are the important roles and actors of the building client organisation in this knowledge transfer process?

RQ 2: Which difficulties in the operation stage of new buildings are facilities managers concerned about, and how may these concerns affect the integration of operational knowledge into design, including the involvement of operational staff?

RQ 3: What can be learnt about the integration of operational knowledge into design by comparing projects for buildings and large ships?

The relationships between the six papers and the RQs are shown in table 1. RQ 1 is answered by paper A and B and partly F, RQ 2 by paper C and D, and RQ 3 by paper E and F. Papers A-D only concern buildings, while papers E and F concern both ships and buildings.

Table 1 Overview of papers included in this thesis and the RQs they relate to

Paper	**Reference**	**Key words**	**Research aim of the paper.**	**Adds to RQ**	**Empirical context**
A Journal, published	Rasmussen, H. L., Jensen P. A., Nielsen S. B. and Kristiansen A. H. (2019) 'Initiatives to integrate operational knowledge in design: a building client perspective', Facilities, 37(11/12), pp. 799–812.	Sustainability, Facilities management, Energy efficiency, Knowledge transfer, Building design, Performance gap	This paper identifies the initiatives a building client can take to integrate operational knowledge in building design. Moreover, it investigates which parties are in the best position to implement the various initiatives.	RQ 1	Buildings
B Journal, published	Jensen, P. A., Rasmussen, H. L. and Chatzilazarou, S. (2019) 'Knowledge transfer between building operation and building projects', Journal of Facilities Management, 17(2), pp. 208–219.	Project management, Knowledge transfer, Building projects, University Campus, Building operation, Building client	This paper examines the transfer of knowledge concerning operation and maintenance (O&M) between the parties responsible for building operation and new building projects.	RQ 1	Buildings
C Journal, published	Rasmussen H. L., and Jensen P. A. (2020) 'A facilities manager's typology of performance gaps', Journal of Facilities Management, 18(1), pp. 71-87.	Performance gap, Building performance, Facilities management, Building operation	This paper investigates what types of performance gaps – besides the energy performance gap - facilities managers are concerned about in new building projects. Furthermore, what implications the interrelation between the types of gaps have on the involvement of FM in new building projects.	RQ 2	Buildings
D Con-ference, published	Rasmussen, H. L. and Due, P. H. (2019) 'The legacy from construction to FM: The good, the bad and the ugly', in Proceedings of EFMC in Dublin, Ireland, June 2019.	FM, Facilities management, FM difficulties, Performance gaps, Construction projects, Building performance	This paper aims to identify specific difficulties experienced by facilities managers in new buildings in Denmark. Moreover, it aims to rank the identified difficulties in accordance to which difficulties facilities managers experience most and least frequently in new buildings in Denmark.	RQ 2	Buildings
E Con-ference, published	Rasmussen, H. L. and Jensen P. A. (2018) 'Tools and methods to establish a feed-forward loop from operation to design of large ships and buildings', in Proceedings of EFMC in Sofia, Bulgaria, June 2018.	Operational knowledge, Building design, Ship design, Construction projects, Knowledge transfer	This paper compares how a feed-forward loop from operation to design is established in projects of buildings and large ships. The paper investigate tools and methods, and whether they reflect a behavioural or technocratic approach to knowledge transfer. Moreover, the paper investigates and compares the general conditions that may affect the establishment of a feed-forward loop.	RQ 3	Buildings and ships
F Journal paper, accepted for publication	Rasmussen, H. L. (forthcoming) 'The challenge of integrating operational knowledge in building and ship design', accepted for publication in a special issue of Facilities.	Operational knowledge, Knowledge transfer, Facilities management, FM, Design, Building design, Ship design, Matter of concern	The aim of this paper is to investigate how operational knowledge is integrated in design, by comparing projects of buildings and large ships. Specifically, the paper investigates how competence, affiliation and matter of concern of a client's project manager influence the efforts made to integrate operational knowledge in design.	RQ 3 (+RQ1)	Buildings and ships

1.3 Research scope and delimitation

As demonstrated in the previous section, the aim of this research touches upon a number of terms and concepts from the construction management, FM, knowledge management and building performance research streams. Thus, delimitations of the study were necessary and are further elaborated on here.

1.3.1 Life stages of building and ship projects

Facility performance is influenced by actions and decisions made in every life cycle of design, construction and operation (Frei *et al.*, 2017). However, since researchers have found that the design stage has the greatest impact on facility performance (Arditi and Nawakorawit, 1999; Le and Brønn, 2007; Loosemore and Chandra, 2012; De Silva *et al.*, 2018; Khalid *et al.*, 2019), I focus on the design process, as illustrated in Figure 1.

Focusing on the design process leads to focusing on the main actors involved in this stage - design teams and project managers. As the topic under investigation is the integration of operational knowledge into the design process, I also focus on those actors who hold operational knowledge - operational staff or others. Despite the fact that user involvement plays an important role in facility performance (Fronczek-Munter, 2016) it is included only to a limited degree. Similarly, the integration of knowledge within the design team, e.g. architects and engineers, is important for facility performance - however, this is not within the focus of this study. Figure 1 illustrates the delimitations of the project in terms of people and process.

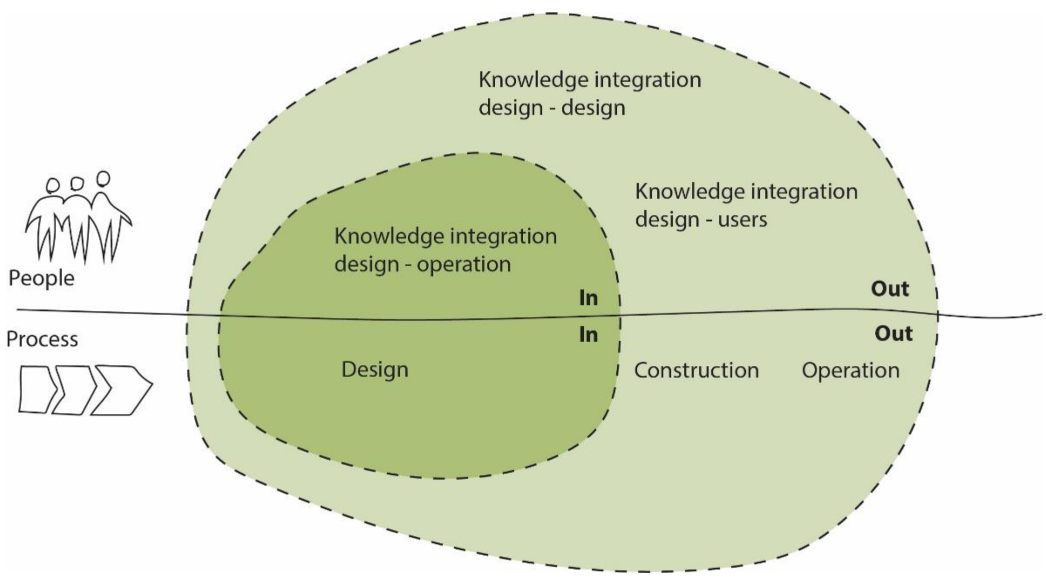

Figure 1 Project delimitations in regards of people and process.

1.3.2 Knowledge from operation to design but not the opposite

Furthermore, delimitations were applied to the 'direction' of knowledge integration. The focus of this study is the integration of knowledge from operation into design and not the other way around, which has been more researched (Jensen, 2009; Rasmussen *et al.*, 2017). Studies have highlighted that early involvement of operational staff eases the handover as the staff becomes familiar with a facility and gives the operational staff ownership of the new facility (Adeyemi *et al.*, 2019). Thus, obviously, it is not possible to completely separate integration of knowledge from operation to design and from design to operation. However, the focus of this study with respect to knowledge direction is from operation to design as illustrated in Figure 2.

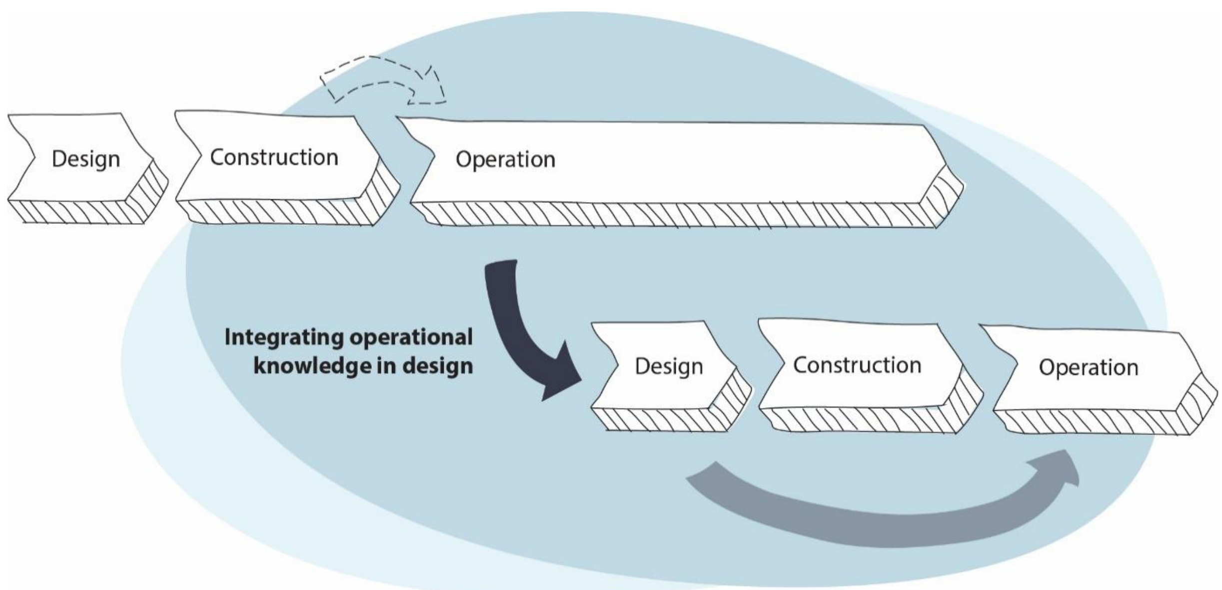

Figure 2 The focus of this research is on the integration of knowledge from operation into design rather than from design or construction into operation.

Moreover, the clients who build to occupy, operate and serve customers/others are the focus in this study. Additional barriers to integrating operational knowledge into design exist if the client is not the occupier (Jauntzen, 2001). More specifically, those organisations with internal operation divisions are focused upon.

Finally, measuring or calculating the effects of specific tools or methods on specific performance parameters was never a part of this study, as the task appeared to be impossible due to the nature and complexity of construction projects. Furthermore, the project also did not aim to measure, calculate or compare the size of performance gaps in the two industries.

1.4 Definition of key concepts

1.4.1 Life stages of building and ship projects

Building and ship projects go through similar life stages: design, construction and operation (Knotten *et al.*, 2016). In recent years, it has been emphasised that the end-of-life stage also needs to be considered a part of the life cycle of buildings (Maslesa *et al*., 2018). However, for the purpose of this thesis, the life stages discussed are limited to design, construction and operation.

The design stage consists of a number of sequential sub-stages, with increasing levels of detail in both ships (Gernez, 2019b; Mallam *et al.*, 2015) and buildings (Fronczek-Munter, 2016; Kelly and Male, 1993; Kolltveit and Grønhaug, 2004). The number and definitions of design stages regarding buildings vary across guidelines and national standards but most include variants of strategic decision, brief/specifications, concept design and detailed design (Fronczek-Munter, 2016). For ships, the stages are often specified as those of basic design and detailed design (Mallam *et al*., 2015). In this thesis, the term design process describes the *entire* process - from strategic decision to detailed design - thus providing a very broad definition. The terms designers and design team are defined as those involved with designing a building or ship - architects, engineers, interior designers, etc. A building client usually appoints one or more project managers to oversee the completion of their project. The project manager is responsible for completing the project within the agreed time, cost and quality (Winch, 2010) and holds contracts with both design and construction teams. The project manager usually refers to either a steering committee or top manager (Winch, 2010).

The study of the second life cycle stage, construction, is limited in this thesis because the study's aim is to investigate the integration of operational knowledge into the design process. Again, I apply a very broad definition by considering the construction stage to span from when models or drawings and descriptions are handed over by a design team to a construction team and until the constructed building or ship is handed over to the client and the client's operation or facilities management team. A previous comparison identified differences in the construction process - e.g. that prefabrication is applied to a higher degree in ship construction (Knotten *et al.*, 2016).

The third stage, operation, is by far the one stage that has the longest timespan for both buildings and ships. Operation includes every aspect of managing and maintaining a facility 'running' and enabling it to fulfil its purpose - whether it be providing office space for a large number of employees or moving goods from one coast to another. Along the same lines, I define operational knowledge as knowledge about managing and maintain a facility 'running' and enabling it to fulfil its purpose. Facilities management (FM) is precisely about managing and operating facilities, including the services needed to support a core business (Jensen, 2008). Despite the fact that the term FM, in my opinion, is to some degree applicable to ship operation, I have found almost no use of it in relation to ship operation in the literature or by my interviewees. Consequently, I refrain from using the term when comparing buildings and ships.

1.4.2 Facilities management (FM)

FM is a support function that takes care of the services and physical surroundings needed for a core business to function. FM is often defined as being related to the people, processes and places of the core business (Jensen, 2008). In this thesis, I adopt Jensen's statement of the close relation between the core business and FM: 'FM is evidently defined as secondary production or support business which…must be considered in connection with the primary business or the core functions which are supported' (Jensen, 2008, p. 10). The papers, which constitute a part of this thesis, cover different aspects of FM. However, the focus is largely placed on operational tasks, as illustrated in Figure 3.

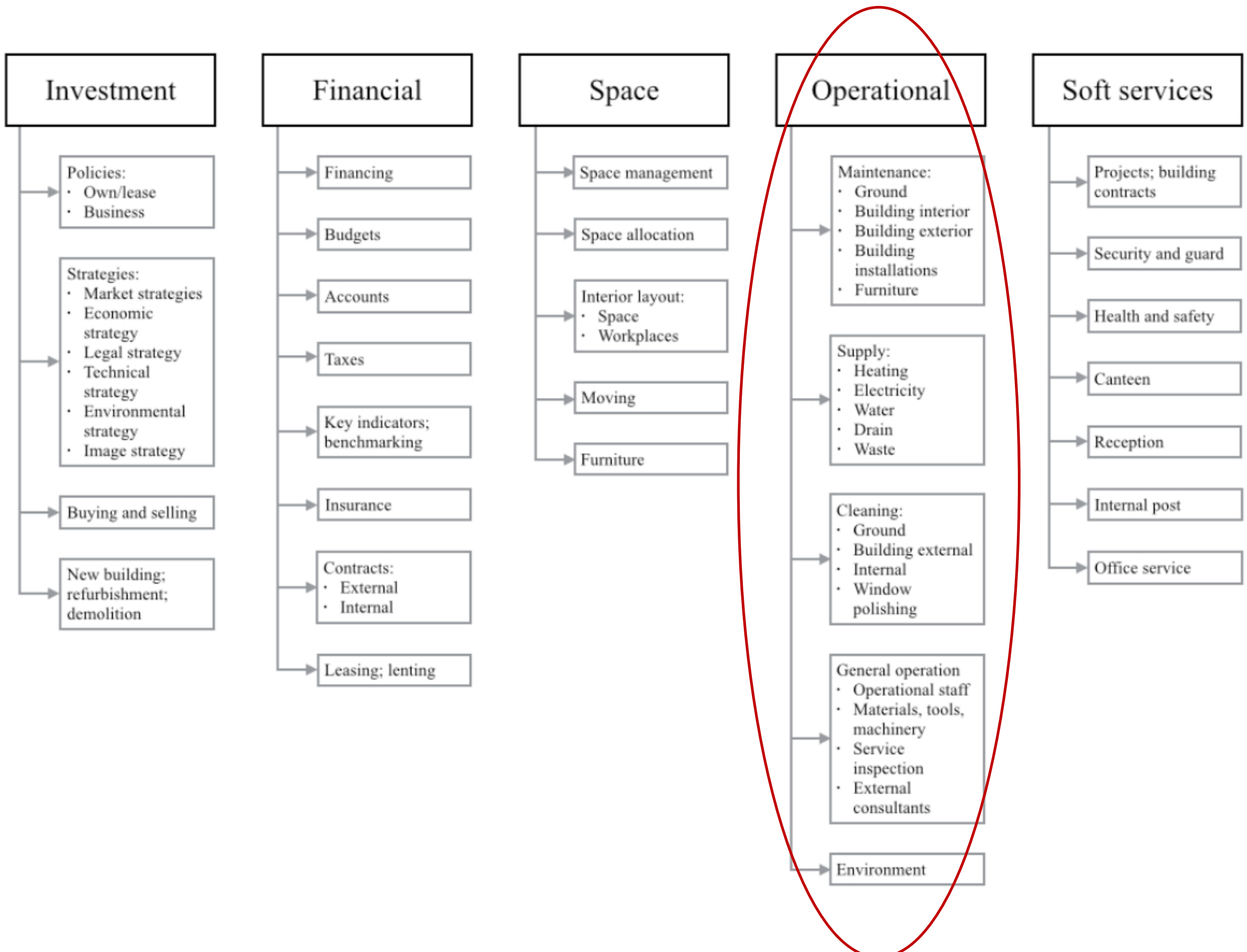

Figure 3 FM tasks (Jensen, 2008; Nardelli, 2014).

FM acts on three levels: operational, tactical and strategic (Jensen, 2008). The strategic task has a long term perspective and includes developing an FM strategy in compliance with the strategy of the core business or organisation. The tactical level implements strategic decisions, policies and guidelines and leads the FM team. The FM tasks at the operational level include daily operation of facilities and delivery of services (European Committee for Standardization, 2006; Jensen, 2008).

In the literature, the term 'operational' describes one of the three levels of actions (operational, tactical and strategic), as well as actions concerned with operational tasks (Figure 3), which clearly brings a risk of confusion in regards of 'operational staff'. Consequently, I define operational staff as follows: Employees carrying out activities that concern the operational tasks typically employed in an operations division, including employees at the operational, tactical and strategic levels.

1.4.3 Knowledge transfer or knowledge integration

I consider *transfer* to be the action of moving knowledge or information and view *integration* as the reuse of knowledge, i.e. the action of using existing knowledge in decision-making or design proposal development, for instance. As I developed greater awareness of the difference between transfer and integration during my studies, I used the term transfer in the initial papers. Furthermore, when referring to the work of other researchers, I adopted the term used by the researcher, which is often transfer.

1.4.4 Users or operational staff

During my studies, I found that operational staff/crew members of ships are often described as 'users' (Osterman *et al.*, 2016), whereas a clear distinction between core business staff and FM staff is often applied in buildings (Jensen, 2008). In this thesis, operational staff indicates those who operate a building or ship. 'Users' includes both the core business staff of buildings and the 'third part' users, such as customers, travellers and patients.

1.4.5 Building and ship performance and performance gaps

Researchers have not settled on a clear definition of building performance. However, the concept of Total Building Performance offers a broad definition that includes spatial quality, thermal quality, air quality, acoustic quality, visual quality and building integrity (Loftness *et al.,*2018; Vischer, 2018). On the contrary, the performance *gap* is very narrowly defined in a stream of literature as the discrepancy between expected and actual energy consumption (Wilde, 2014; Ornetzeder *et al.*, 2016; van Dronkelaar *et al.*, 2016; Gram-Hanssen and Georg, 2018; Mallory-Hill and Gorgolewski, 2018). Thus, the definition of a *gap* only addresses a limited topic within building *performance*. This is problematic in terms of understanding the integration of operational knowledge into design and an entire paper is devoted to this topic, on its own - Paper D.

Similar to building performance, ship performance is not a fixed term but has been categorised as 'propulsive performance, safety performance, seakeeping performance, manoeuvring performance' (Tsujimoto and Orihara, 2019, p. 16). Also similar to building performance, ship performance depends on design, construction and operation (such as speed and load). Furthermore, unlike buildings, ship performance is further influenced by external conditions, such as wind and waves (Tsujimoto and Orihara, 2019).

In brief, performance and performance gaps of both buildings and ships are defined here more broadly than in the literature in general.

1.5 Structure of the thesis

This paper-based thesis consists of six individual papers and a synopsis that ties them and their findings together to fulfil the overarching research aim and investigate how operational knowledge is integrated into the design process of buildings in comparison to large ships, aiming to improve facility performance.

The synopsis is structured as follows:

Chapter 1 introduces the thesis, including the topic of integration of operational knowledge in design. I also present the research questions, scope and definition of terms in this chapter.

Chapter 2 provides the theoretical background, presenting theories of knowledge management and knowledge transfer and further outlines the state of the art of the literature on integration of operational knowledge into the design process in building projects and, briefly, ship projects and on performance gaps. It also presents literature on information overload, bounded rationality and matter of concern.

Chapter 3 outlines the methodological approach and presents the five sequential method parts of this study: literature review, expert interviews, workshops and focus group interviews, a questionnaire survey and the multiple case study.

Chapter 4 provides a brief summary of each of the six papers.

Chapter 5 ties together the 6 research papers answering the three sub research questions.

Chapter 6 concludes the thesis by answering the main research question. Moreover, chapter 6 outlines my contribution to the literature and implications for practise. Finally, recommendations to further research is provided in chapter 6.

2. Theoretical background

This section presents the relevant theoretical background from the research field of knowledge management, mostly limited to the notion of knowledge transfer (section 2.1). Following, the state of the art of the literature related to knowledge transfer from operation to building design is outlined in section 2.2. A subsection (2.2.3) includes a brief presentation of literature on the integration of operational knowledge into ship design. Section 2.2.5 introduces the concepts of information overload, bounded rationality and matter of concern. Finally, section2.3 provides a summary of the state of the art of the literature regarding performance gaps in new buildings by resuming the literature review included in Paper C.

2.1 Knowledge management and knowledge transfer

2.1.1 Knowledge management - Two perspectives

The definition of knowledge has been widely discussed in the knowledge management literature (Kreiner, 2002; Vianello, 2011) and with good reason - since researchers' definitions of knowledge strongly influence the way they consider knowledge to be managed and, thus, transferred.

The definition of tacit and explicit knowledge (Polanyi, 1966) is as widely discussed as the definition of knowledge itself. Explicit knowledge is accessible to others through reports, drawings, check lists, instructions, etc. Tacit knowledge, on the contrary, is personal and is thus not easily explained to nor accessed by others – sometimes not even by oneself. Tacit knowledge is the knowledge we are not highly aware of and it includes intuition and hunches (Pan and Scarbrough, 1999; Nonaka *et al*., 2000; Hislop *et al., 2018)*.

Hislop *et al*. (2018) find that two perspectives of knowledge dominate the literature - the objectivistic perspective and the practice-based perspective. The objectivistic perspective on knowledge is rooted in positivism and those who adopt this perspective consider tacit and explicit knowledge as two different types of knowledge. They trust that knowledge can be objective and value explicit knowledge over the more subjective tacit knowledge (Hislop *et al.*, 2018).

The practice-based perspective defines knowledge differently from the objectivist perspective. This definition is, according to Hislop (2018), based on five assumptions about knowledge that stipulate that knowledge is: embedded in practice, multidimensional, embodied in people, socially constructed, culturally embedded and contestable. In contrast to the objectivistic perspective, which is based on a positivistic epistemology, the practice-based perspective covers different epistemological approaches (Hislop *et al.*, 2018) and, as such, represents a broad and somewhat mixed category.

Alvesson and Kärremann (2001) make a similar distinction between the two knowledge management approaches: 'In particular knowledge management focuses on the creation and distribution of knowledge in organizations through technological novelties such as the internet, intranets, and e-mail, though there are also streams concentrating on social relations and interactions' (p. 995). They distinguish between those interested in the 'technological side' of knowledge management and those interested in the 'people side' (Alvesson and Kärreman, 2001).

Earl (2001) presents yet another set of terms for two similar approaches: the technocratic and behavioural approaches. In fact, he identifies seven knowledge management schools and gathers them under the umbrella terms of technocratic and behavioural schools. He further defines a third school - the economic school - but, with respect to the topic of operational knowledge in design processes, the two main schools utilising the technocratic and behavioural approaches sufficiently cover the perspectives on knowledge management. One must, of course, bear in mind that discussing approaches (and not just the seven described by Earl) as either technocratic or behavioural is a simplification. Previous studies on operational knowledge in design have benefited from adopting Earl's technocratic and behavioural approaches (Vianello, 2011; Vianello and Ahmed, 2012), which is why I also adopt these terms in this thesis.

Researchers within the behavioural school also discuss tacit and explicit knowledge. However, they do not consider them to represent two opposite types of knowledge but rather as dimensions of knowledge itself (Brown and Duguid, 2001). They advocate that all knowledge is tacit (Kreiner, 2002), which certainly influences the way they consider knowledge to be (un-)manageable and (un-)-transferrable and is something that I will come back to later. Furthermore, Kreiner (2002) states that the so-called codified knowledge is simply information (Kreiner, 2002).

The distinction between information and knowledge is another relevant topic in the knowledge management literature. One take on this is the hierarchic four-level model of data – information – knowledge - wisdom, which follows the assumption that data and information are not knowledge in itself (Vianello, 2011). According to Vianello, the literature on knowledge transfer within engineering management tends to focus on the transfer of data and information, whereas the knowledge management literature focuses more on the upper levels - knowledge and wisdom (Vianello, 2011).

2.1.2 Knowledge transfer - Two perspectives

As a natural part of managing knowledge, the act of transferring and sharing of knowledge has been widely studied. Knowledge transfer in organisations has been defined as: 'the process through which one unit (e.g. group, department, or division) is affected by the experience by another' (Argote and Ingram, 2000, p. 151). Furthermore: 'Knowledge transfer in organizations manifests itself through changes in the knowledge or performance of the recipient units' (p. 151). Moreover, the authors also state that, as the change in knowledge is difficult to measure, the success of the knowledge transfer should be measured through increased performance at the receiving part.

Whereas some researchers investigate knowledge transfer within homogeneous groups, such as Communities of Practice in which members share a sense of identity, values and knowledge, other researchers stress the increasing complexity when knowledge needs to cross boundaries (Brown and Duguid, 2001; Carlile, 2004; Hislop *et al*., 2018), such as those of disciplines (Vianello and Ahmed, 2012). In construction projects, knowledge needs to cross boundaries between project stages and between groups of actors. In addition, in ship projects, knowledge often needs to cross large geographical boundaries (Knotten *et al.*, 2016). This increase the complexity of knowledge transfer, as different actors may have limited shared sense of identity, values and knowledge, which research have identified as prerequisite for knowledge transfer (Davenport *et al.*, 1998). On the other hand, it also presents an opportunity to create new knowledge and innovation (Hislop *et al.*, 2018). To ensure the benefit of cooperation across different knowledge bases, the strategy to ease difficulties across boundaries is, according to Hislop, to develop a mutual understanding and social relationships between different parties. The aim is not to assimilate one part to the other but for each part to maintain 'its own voice' (Hislop *et al*., 2018 p. 228, referring to Gherardi and Nicolini, 2002).

The two perspectives of knowledge, embodied in the technocratic and behavioural approaches, present different views on how knowledge can be managed and, thus, transferred. I have used the metaphors of a bird and a suitcase to describe these two approaches to knowledge transfer in popular articles (Rasmussen, 2018) and presentations (see the list of other publications and list of presentations in appendices). The suitcase is a metaphor for the technocratic approach and bird for the behavioural approach (Figure 4).

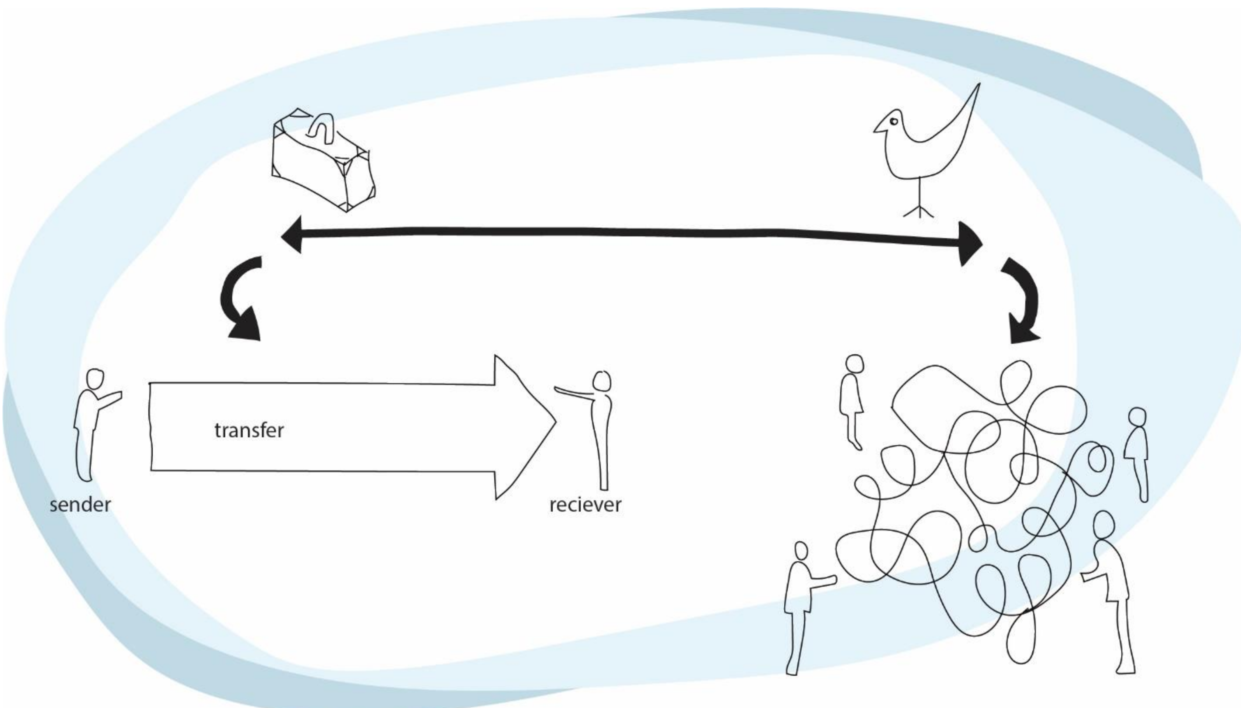

Figure 4 Bird and suitcase metaphor for knowledge transfer approaches.

The technocratic approach, for which I have used the suitcase metaphor, finds that knowledge can be codified and thus made explicit. With that as the starting point, a number of models for knowledge transfer have been developed (Zuo *et al.*, 2013). They are based on the assumption that there is a well-defined sender as well as a receiver of knowledge as illustrated in figure 4. They provide models that include the following steps: 1) codifying/externalising 2) knowledge storage (now detached from the knowing person) and 3) applying or reusing the knowledge in a new context (Davenport *et al.*, 1998; Reihlen and Ringberg, 2006). Requisites to successful knowledge transfer are a structure for the codified knowledge, a suitable container (a suitcase) - often an IT tool such as a database (Davenport *et al.*, 1998) - and 'timing' (the right time and place) for receiving knowledge. Additionally, the willingness or motivation of individuals to send and receive knowledge has been emphasised (Davenport *et al.*, 1998; Hislop, *et al.*, 2018; Zuo *et al.*, 2013).

For an example of a sender-receiver-based model, Wong (2008) presents a model of knowledge transfer. This model is a slightly different from others because it promotes a link back to wherever knowledge is created. However, Wong's definition of knowledge leaves no doubt about its basis on the technocratic approach: 'We believe that knowledge is relevant information delivered at the right time and context' (Wong *et al.*, 2008).

The behavioural approach, for which I have used the bird metaphor, stresses that knowledge, being embedded in the knowing person, is unlikely to be transferred detached from the knowing person. Consequently, it does not suggest linear processes of transferring knowledge from a sender to a receiver. In fact, those aligning with this approach are not occupied with developing models to transfer knowledge. Nevertheless, I illustrated the behavioural approach to knowledge transfer in Figure 4, which gives an illustration that I have used in various presentations on this topic. The illustration must clearly be seen as a pedagogical illustration intended for communication more than anything else.

The knowledge conversion model of Socialisation, Externalisation, Combination and Internalisation (SECI) (Nonaka *et al*., 2000) has received much attention from knowledge management researchers (Martin and Root, 2009; Hislop *et al*., 2018; Kahrens and Früauff, 2018). The process of knowledge conversion is described as a spiral movement shifting between the four modes of knowledge conversion. Thus, the SECI model is an example of a non-linear model, and one could argue that it is based on a behavioural approach. The transformation of tacit knowledge into explicit knowledge remain an important step, thus more similar to the technocratic approach (Hislop *et al*., 2018). However, in Nonaka's work, explicit and tacit knowledge are defined as two dimensions of knowledge along a continuum, rather than distinct and opposite types of knowledge (Nonaka and von Krogh, 2009).

The first mode of the SECI model is socialisation, which concerns the conversion of tacit to tacit knowledge. It consist of the interpersonal sharing of tacit knowledge through social interaction. Externalisation concerning the conversion of tacit to explicit knowledge is the second mode. In this mode, tacit knowledge is made accessible to others in words, drawings etc. Combination, the third mode, is conversion of explicit to explicit knowledge. This mode concerns the integration of different forms of explicit knowledge. Internalisation, the fourth mode, concerns the conversion of explicit knowledge into tacit knowledge: In this mode, explicit knowledge is 'absorbed' (Hislop *et al.,* 2018 p. 117), thus integrated in the work and practices of individuals (Nonaka *et al.* 2000).

Carlile (2004) argues that the term 'transfer' is inherited from a sender-receiver approach based on a technocratic approach to knowledge transfer and stresses its tendency to underestimate the complexity of knowledge movement across borders. He defines transfer as the simplest form of knowledge movement, whereas knowledge translation and knowledge transformation are more suitable for understanding the complexity of the phenomenon (Carlile, 2004).

Pan and Scarbrough (1999) present a study based on the behavioural approach. Here, knowledge is defined as socially constructed and organisational knowledge is seen as the interplay between technical and social factors. Knowledge is created and transferred not from a sender to a receiver but in social interactions and conversations. A shared vision for both knowledge sharing and managerial efforts to create a culture of knowledge sharing is found important for transfer of knowledge to take place. Like the technocratic approach, the behavioural approach stresses the importance of willingness and motivation for transferring and sharing knowledge.

Hansen *et al*. (1999) find that it is not a matter of choosing one approach over the other because each suit different contexts. Hansen *et al*. present two management strategies that an organisation can choose from, which is very much in line with the technocratic and behavioural approaches-the codification strategy and the personalisation strategy. As its name reveals, the codification strategy implies making knowledge explicit and codified - and thus possible to store, transfer and reuse by others. On the contrary, the personalisation strategy implies social interaction and establishing a culture for knowledge sharing. If an organisation works with customised and innovative products and spreads out to more business units, a personalisation strategy is most suitable (Hansen *et al.*, 1999; Hislop *et al*., 2018).

The two perspectives must not be boiled down to a question of written communication or face-to-face communication, as both perspectives acknowledge the need for social interaction in order to transfer knowledge. Moreover, face-to-face meetings can also be based on a technocratic approach with a strong focus on a sender and a receiver. However, the codification of knowledge is a fundamental part of knowledge transfer in the technocratic approach. Kahn differs between *interaction* and *collaboration* (Kahn, 1996). *Interaction* represents the formal, structured and measurable activities across a department, including both documentation and face-to-face meetings. On the contrary, *collaboration* refers to informal and unstructured activities through which departments develop mutual understanding and common goals. An organisation does not need to choose but can use the two to complement each other (Kahn, 1996).

Knowledge repositories/reservoirs

Knowledge transfer studies based on both technocratic and behavioural approaches discuss 'containers' of knowledge. Davenport *et al.* (1998) describe repositories for both structured and unstructured organisational knowledge and refer to IT tools. Argote and Ingram (2000) introduce knowledge *reservoirs*-members, tools or tasks.

Although Argote and Ingram distinguish between tacit and explicit knowledge, they do not present a stepwise sender-receiver model. Instead, they suggest that knowledge can be transferred in two ways: either by moving a repository to a receiving unit or by modifying a repository at the receiver unit. Furthermore, they highlight the need for similarities in members, tools or tasks at the sender and receiver units in order to accomplish the transfer of knowledge (Argote and Ingram, 2000). One way of transferring knowledge is to move a reservoir from one unit to another unit - e.g. a member. Moving a member is an efficient way to transfer knowledge because individuals bring both tacit and explicit knowledge and additionally hold the ability to transform knowledge in order to make it applicable in a new context, which also leads to the creation of new knowledge. A threat to this efficient way of transferring knowledge is that the moved person often becomes a minority in the new unit, which might limit the efficiency of the transfer (Argote and Ingram, 2000).

Different interests and incentives

When knowledge is crossing boundaries, the complexities and challenges increase. Carlile (2004) stresses the need for using a common language and having a common meaning, which is required in order for knowledge to be moved. This, he states, is well embraced by researchers, including the SECI model (Nonaka *et al*., 2000). However, adding further complexity to the matter of moving knowledge across boundaries, there are also the different interests that participants across boundaries might have in projects. Different interests need to be negotiated in order for common interests to be defined. Carlile states: 'When interests are in conflict, the knowledge developed in one domain generates negative consequences in another' (2004, p. 559). Thus, in order to assess knowledge across boundaries, common language, understanding and interests need to be developed.

In a comprehensive study of literature, Zuo *et al*. (2013) identify three interrelated kinds of knowledge transfer mechanisms - means, process and governance of knowledge. Governance mechanisms include incentive institutions, which are found to be important for the motivation to both send and receive knowledge. 'These incentive factors can be divided in to intrinsic and explicit ones. The former appears to be more important to the transfer of tacit knowledge…however, both of them will have affect the willingness and behaviour of knowledge transfer, and furthermore promote knowledge transfer directly' (Zuo *et al*, 2013, p. 68). As many other researchers, Zuo *et al*. further stress the importance that culture and trust have on the willingness to transfer knowledge.

2.2 Knowledge transfer from operation to design

Knowledge transfer in construction projects is not a new research topic. Around 10 years ago, researchers concluded that, even though the challenge of integrating operational knowledge into design was not a new topic, it had received little attention from researchers (Le and Brønn, 2007; Jensen, 2009). Since then, the topic has gained increasing attention (Kalantari *et al.*, 2017) and much important work has been carried out to gain more insight into the topic. In this section, I account for the state of the art of literature on the integration of operational knowledge first in building projects and, second, in ship projects and other engineering projects, albeit briefly.

2.2.1 Knowledge transfer from operation to building design

Despite increasing attention, different researchers investigate the phenomenon of integrating operational knowledge using various terms - such as feedback (Cohen *et al.*, 2001; Way and Bordass, 2005; Le and Brønn, 2007; Kristiansen, 2010), feed-forward (Jensen, 2009), early FM involvement (Meng, 2013) and knowledge transfer (Jensen, 2012; Adeyemi *et al.*, 2019). Furthermore, FM has been called the missing link between building operation and building design (Jensen, 2009, 2012). The lack of unified terminology poses an academic challenge because important research work is scattered and there is a risk that new research misses important results of earlier work.

I find that the various terms describe the same phenomenon. However, Jensen (2009a) makes a distinction between feedback (citing Bröchner, 1996) from the operation team about the design of a particular building and the feed-forward loop from existing buildings (in general) to new buildings.

Importance of the early stage of building projects

Building projects, like ship projects, have a linear process of realisation; thus, decisions made and actions taken during one stage impact the subsequent stages. The design stage is not the only important stage for ensuring optimised performance, as other studies find that action during each life cycle stage affects the overall performance of a building (Arditi and Nawakorawit, 1999) and the involvement of FM should not be limited to the design stage alone. In addition, studies outline FM tasks for all stages of a building project (Jauntzen, 2001; Hansen *et al.*, 2010).

However, the design stage (including early planning and briefing in my broad definition) has been pointed out as especially crucial for the performance of the finished facility (Arditi and Nawakorawit, 1999; Le and Brønn, 2007; Loosemore and Chandra, 2012; De Silva *et al.*, 2018; Khalid *et al.*, 2019). Design errors have been identified as one of the main factors of FM cost performance (Islam *et al.*, 2019). Furthermore, studies of sustainable FM show that sustainable operation depends on operational considerations made during the design stage (Meng, 2014; Zainol *et al.*, 2014; Ganisen *et al.*, 2015; Nielsen *et al*., 2016; Chew *et al.*, 2017).

The early stages of construction projects are characterised by high uncertainty and involvement of many stakeholders, potentially with different interests and needs in these projects, which have to be balanced (Kolltveit and Grønhaug, 2004; Loosemore and Chandra, 2012). Consequently, the project team must balance operational considerations with other considerations.

Building client as a key for ensuring the integration of operational knowledge into design

Building clients or representatives for building clients have been pointed out as being key actors for ensuring that operation is taken into consideration in the design stage (Jensen, 2009; Fatayer *et al.*, 2019). The building client is often the only actor taking part in all the stages of a project, whereas design teams or contractors are only involved in some stages (Hansen *et al.*, 2010). The building client sets the requirements for the project and has the position to raise awareness of operation in the project (Jensen, 2012). To ensure that operation is taken into consideration in the design process, it has been suggested that operational staff - or facilities managers - should be placed in prominent positions in new projects (Erdener, 2003; Loosemore and Chandra, 2012).

Barriers to integrating operational knowledge into building design

As FM evolves as a profession, the acknowledgement of the value of its contribution to design increases (Meng, 2013; Kalantari *et al.*, 2017). However, studies conclude that the involvement of FM in building projects is limited in practice (Jensen, 2009; Lindkvist, 2018).

Barriers to integrating operational knowledge into design have been mapped in a Danish study based on literature reviews and in-depth interviews (Damgaard and Erichsen, 2009). The identified barriers are spread into five categories: project-related, structural, legislative, competence-related and sociological (Damgaard and Erichsen, 2009; Hansen *et al.*, 2010). Project-related barriers include temporary teams, where a new design team is gathered for each project, and the challenge of placing the responsibility for difficulties in operation. Structural barriers include the distinction between opex and capex as well as the short-term perspective in building projects. Legal barriers include lack of legislation and tender legislations. Competence-related barriers include operational staff's lack of communicative skills and lack of expertise on building operation. Sociological barriers include power relations, weak relations between operational staff and the design team and operational concerns as being less prestigious (Damgaard and Erichsen, 2009).

Thus, almost every characteristic of construction projects has been identified as a barrier to knowledge transfer from operation to design, including the on–off production style and the increasing complexity of projects (Hansen *et al.*, 2010; Kristiansen, 2010). The separation of stages, where one set of actors is experienced with the work during one project stage but not the next one, and the fact that design teams rarely experience the operation of the projects they were responsible for designing (Lindkvist, 2018) also limit operational considerations in the projects.

A lack of operational staff competences in building projects has been pointed out as a barrier to integrating the knowledge of operational staff into design processes (Damgaard and Erichsen, 2009; Jensen, 2009). In addition, the actors' perception of the ability of the operational staff to contribute to the design process has further been identified as a barrier (Jauntzen, 2001). Moreover, the cultural differences between those who operate and design a building have been identified as barriers to knowledge transfer between the two (Damgaard and Erichsen, 2009; Jensen, 2012). Furthermore, the design teams typically tend to have academic backgrounds, whereas the operational teams have very different backgrounds (Jensen, 2012).

Different perspectives on and interests in the project

Another barrier for successful and efficient integration of operational knowledge into design processes is the actors' different perspectives on the building project (Jensen, 2012; Whyte *et al.*, 2016; Lindkvist, 2018). Operational staff have a long-term perspective on a building project, where completing a project represents only the beginning of a building's life. On the contrary, design teams and project managers have a short-term perspective on a building project, where completing a project means finishing the job and moving on to the next project. Johnston *et al*. (2007) describe these cultural differences using the metaphor of *hunters* for the project team members and that of *farmers* for the maintenance team members.

In addition to short- and long-term perspectives, different actors involved in a project have different goals, which makes it challenging to create shared project goals (Arditi and Nawakorawit, 1999; Lindkvist, 2018; Lindkvist *et al.*, 2019). Thus, as designers have many considerations to balance, operations are not prioritised (Arditi and Nawakorawit, 1999). Following the same line of thought, Elmualim *et al*. (2009) find that actors in construction projects primarily seek to meet their specific needs. This is supported by Hansen and Damgaard (2012), who state that 'The integration of facilities management knowledge in problem solving to a high degree depends on the architects' and engineers' interest and capability to do so' (p. 280).

Recommendations on giving FM 'a stronger voice'

In addition to tools and methods for ensuring the integration of operational knowledge in design, researchers also recommend that building clients raise FM awareness in their building projects (Jensen, 2012). In Jensen's (2012) typology for knowledge transfer between operation and design, two ways of ensuring that the design team integrates operational knowledge are identified - increasing awareness and using power. Power refers to the fact that a building client has the possibility to demand certain actions from the design team, whereas awareness is more in line with inspiring the design team to take certain actions with the aim of integrating operational knowledge in the design process.

Although operational staff are professionals within their own field, they are not necessarily professionals regarding design processes. This constitutes a barrier (Jauntzen, 2001; Adeyemi *et al.*, 2019) because operational staff can have difficulties in contributing with requirements or comments at an appropriate stage. Furthermore, the lack of insight into the design processes potentially makes operational staff appear to be vague and incompetent when involved in them. This has led to the recommendation that operational staff should increase their competences within design and construction in order to get a stronger voice in projects.

Tools and methods for transferring knowledge from operation to design

With the aim of ensuring that operation is taken into consideration by a project's team, various tools and methods for this purpose to have been developed. Some of these are based on the direct involvement of people with experience in building operation (Jensen, 2009). They can be members of a building client's internal operational staff (Whyte *et al*., 2016) or external consultants with operational expertise. A design review by operational staff is one example of such a tool (Jensen, 2009; Fatayer *et al.*, 2019), where design proposals are reviewed by either internal operational staff members or external consultants. Design reviews can be carried out at different levels of detail and can be focused on a specific topic, such as technical installation, interior layout and maintainability of building parts (Mohammed and Hassanain, 2010).

Other tools and methods do not necessarily require the direct involvement of people with operational experience because they are, to a large extent, based on operational data or codified knowledge. An example of this is life-cycle costing (LCC) or whole life costing (Saridaki *et al.*, 2019), which is mentioned in the literature as a tool for integrating operational knowledge in the design process (Jauntzen, 2001). LCC is valuable for comparing alternative design solutions from a long-term perspective, where both capex and opex are included (Saridaki *et al.*, 2019).

Building Information Modelling (BIM) (Saridaki *et al.*, 2019) is found to be promising as a container of knowledge from both operation and design arenas.(Jensen, 2009; Göçer *et al*., 2015), but it is often described and researched as containing knowledge that needs to be transferred from project to operation (Whyte *et al*., 2016). Göcer *et al*. (2015) suggest that the Post Occupancy Evaluation (POE) performance evaluation tool is linked to BIM to visualise and store operational knowledge. Computer Aided FM (CAFM) is also indicated to have a large, unexploited potential for collecting and storing FM information, which can be useful in the design process of new buildings (Jensen, 2009).

Lists of more tools and methods recommended by the literature are provided in papers A, B and E.

2.2.2 Knowledge transfer within the FM - two perspectives

Similar to research on knowledge transfer within the field of knowledge management (see section 2.1.2), the research on knowledge transfer between building operation and design has two opposite approaches to knowledge transfer (Rasmussen *et al.*, 2017). On the one hand, there is the research that takes a technical approach to knowledge transfer while, on the other hand, there is the research that takes a behavioural approach to knowledge transfer (Earl, 2001; Vianello, 2011).

As an example of the technocratic approach, the authors of a study that focuses on the efforts of FM organisations to integrate operational knowledge into design (Fatayer *et al*., 2019) recommend that indirect communication is supplemented by more direct dialogue with project participants, including codification and establishing a database to store maintenance issues that could inform subsequent projects. Other studies based on the technocratic approach, suggest the use of BIM to inform design teams (Göçer *et al*., 2015) or the increase of operational data in energy performance modelling (Menezes *et al.*, 2012).These studies do not refer to knowledge management.

Research based on the behavioural approach emphasises the need for social interaction between design teams and operational staff (Hansen and Damgaard, 2012; Meng, 2013; Lindkvist, 2018). Loosemore and Chandra (2012) investigate the briefing process (part of design, in my definition) as a matter of cultural learning and negotiation. They recommend a briefing process that allows participants, including FM staff, to negotiate a common understanding of the project through social interaction (Loosemore and Chandra, 2012).

Yet, other researchers combine the two approaches and emphasise that both technical tools and social interaction are needed to transfer knowledge in large scale projects (Le and Brønn, 2007; Jensen, 2012; Lindkvist *et al.*, 2019). Lê and Brønn (2007) refer to two organisational knowledge management strategies - the codification strategy and the personalisation strategy - which they recommend to be combined in order for knowledge transfer to take place in construction projects (Lê and Brønn, 2007).

2.2.3 Integration of operational knowledge into ship design

Concerning ship projects, researchers have also been investigating how operational knowledge can be integrated into design processes. However, I found the literature on this topic to be limited. Ship design research has a strong technical focus (Gernez, 2019a). The traditional drivers for ship design are powering, stability and seakeeping, leaving the end-users to play a secondary role in it (Mallam *et al*., 2015; Gernez, 2019b). It has been problematised that the ship designers' lack of experience about the sea is a barrier for designing a ship optimised for operation (Mallam *et al.*, 2015),

Recent studies investigate the Human Factors and Ergonomics (HFE) in ship design and emphasise the need to bring those who operate existing ships and those who design new ships closer together in order to increase safety at sea (Lurås and Nordby, 2014; Mallam *et al.*, 2015; Mallam and Lundh, 2016; Gernez *et al*., 2018; Gernez, 2019b). Researchers find that the need to integrate HFE knowledge in ship design is still not fully acknowledged and that new, user-friendly, efficient and easily integrated methods for considering the HFE in the design processes need to be developed (Mallam *et al*., 2015).

'Field studies' are suggested to assist designers in taking operation into consideration during the design process. Field studies represent an ethnographically inspired approach, offering designers the opportunity to become familiar with people at sea, to gain insight into their culture and to understand how and why operational tasks are carried out as they are. In research on field studies within ship design, there is an equal focus on gaining insight and inspiration, aiming at giving designers 'a sense' of life at sea (Lurås and Nordby, 2015)referring to sensemaking (Weick, 2001).

2.2.4 Integration of knowledge into other engineering fields

Due to the lack of existing literature on knowledge integration between operation and design in ship projects, I looked into integration of operational knowledge in other related fields.

In engineering research, studies have succeeded in applying knowledge management theory to shed light on the knowledge transfer processes, from operation to design, within various fields of interest. For example, there are studies on knowledge transfer from service to design in the oil industry (Vianello and Ahmed, 2012; Souza da Conceição *et al.*, 2019) and from maintenance to airplane engine design (Wong *et al.*, 2008; Jagtap and Johnson, 2011). Vianello and Ahmed (2012) investigate the technocratic and behavioural approaches to knowledge transfer (see section 2.1.1) and conclude that the technocratic approach is dominant within the field of knowledge transfer in engineering projects, which is corroborated in my review of the literature within the field of knowledge transfer from building operation to design.

2.2.5 Information overload, bounded rationality and matter of concern

Construction projects involve a large number of people and organisations, which makes coordination between and within organisations extensive and results in the need to coordinate a large amount of information. Furthermore, project participants feel the need for documenting their accountability, resulting in extensive production of documentation in construction projects (Kolltveit and Grønhaug, 2004). The large amount of documentation potentially instigates a negative spiral, where the typical response to documentation overload is the production of even more documentation (Wulff *et al.*, 2000).

Thus, the level of accumulated knowledge - or information - is already extremely high in construction projects. In fact, there is a risk of information overload (Hansen *et al.*, 2010; Winch, 2010; Jensen, 2012;

Hall-Andersen, 2013). This implies that some knowledge or information is wasted or drowned and does not come to the attention of participants. Unread instruction manuals, meeting minutes and e-mails are examples of this (Kreiner, 2005). Additionally, meetings contribute to an information overload that occurs on a project. Kahn stresses that too much interaction in the form of formal meetings and information flow between departments can 'overburden personnel with having to attend too many meetings and [result in] being overloaded with information' (1996, p. 150).

Moreover, humans have limited capacity to consider all information and interests in decision-making. Hence, even if participants do read the manual, the minutes and the e-mails, there is still a risk that they are not capable of including all the knowledge thus gained into the decisions they make during the design process. They have bounded rationality (Simon, 1991).

In situations, where it is impossible for everything to receive equal attention or consideration, what will determine what gets attention? Some researchers discuss the difference between 'matter of fact' and 'matter of concern'(Latour, 2004; Kreiner, 2010). Unlike matters of fact, matter of concern, includes desires (Ripley *et al*., 2009) and are characterised by 'being rich, complex, surprising and constructed'(Brodersen and Pedersen, 2019 s. 966).

In conclusion, I find that the literature on the integration of operational knowledge into building design is mostly based on the technocratic approach, focusing on developing tools and methods and on understanding the barriers to their implementation. Less attention is given to how the transferred knowledge is integrated or to how the project participants are motivated to pick up the knowledge in order to increase building performance. No attention is given to how different FM elements can result in conflicting FM demands, thus challenging the integration of operational knowledge into the design process. Despite the literature on the information overload in construction projects, little attention is given to how it can be ensured that the transferred knowledge is not wasted, as project managers and design teams are already flooded with information.

2.3 Building performance gaps

The main driver for integrating operational knowledge into design is to increase the performance of the new facilities during their operation. This includes preventing performance gaps and unforeseen difficulties in operation to appear. However, the terms *building performance* and *performance gaps* are defined very differently in the literature.

Studies on *building performance* investigate how buildings 'work' and include aspects of their physical as well as social characters. Historically, these two aspects have not often been found in the same studies; however, recently, they are increasingly studied and evaluated together (Støre-Valen and Lohne, 2016). As such, studies on building performance include a variety of performance parameters, including user behaviour and usability (Hansen *et al.*, 2011), spatial quality, aspects of indoor climate, visual quality and building integrity (Loftness *et al.*, 2018). Despite an increasing focus being placed on both physical and social aspects of building performance, evaluation schemes rarely cover all performance parameters in one (Fronczek-Munter, 2013; Støre-Valen and Lohne, 2016).

In comparison, definitions of the *building performance gap* are narrowed in the literature to the discrepancy between the expected energy consumption of a building and its actual energy consumption (Menezes *et al.*, 2012; van Dronkelaar *et al.*, 2016; Frei *et al.*, 2017; Coleman and Robinson, 2018; Gram-

Hanssen and Georg, 2018; Lindkvist, 2018). There has been great political focus on energy performance due to the political agenda (EU, 2016). This possibly explains why this type of performance has received much more attention in research than in practice. Gaps in other types of performance of relevance for FM have also been investigated - not as performance gaps but as performance failures that lead to increased energy consumption, disappointing indoor climate and decreased user satisfaction (Borgstein *et al*., 2018). Furthermore, studies are investigating the challenges of unexpected high operational expenses and negative impacts on core businesses (Boge *et al.*, 2018), as well as FM problems - such as poor operation and maintenance (O&M) material and unfinished construction work (on technical installation in particular) - inherited from building projects, in newly built facilities (Lindkvist, 2018). However, the term performance gap seems to be examined primarily by researchers of energy performance.

Jauntzen (2001) provides a comprehensive list of common operational problems, which she claims that the involvement of FM in the design processes can prevent. The problems are listed in 10 categories, including mechanical and electric service problems, building fabric and landscape problems, layout problems and fire safety problems. Although not listed, Jauntzen emphasises FM's contribution to ensuring that the new facilities support the core business strategies (Jauntzen, 2001). Consequently, Jauntzen's study provides an example of a study that simultaneously includes many different perspectives. However, little attention is given to how they affect one another or to what problems most often occur.

Researchers find that different performance parameters affect each other (Ornetzeder *et al*., 2016; Borgstein *et al*., 2018; Lindkvist, 2018; Mallory-Hill and Gorgolewski, 2018). Thus, research gathering the performance gaps is needed. The lack of such research could potentially lead to a focus on bridging the energy and to some extent the indoor climate performance gaps, with limited awareness of the consequences that actions to prevent performance gaps have on other performance parameters of interest to FM.

3. Methodology

This chapter outlines the underlying assumptions, research approaches and methods, including data collection and analysis, applied throughout the three-year study conducted for the purposes of this thesis. The study was conducted sequentially, in five main steps, as illustrated in Figure 5. Its purpose was to build knowledge up in a manner in which the findings and insights - or puzzles (Schwartz-Shea and Yanow, 2012) - from one step feed into and shape the following steps. Nevertheless, some ontological and epistemological assumptions were shared and developed throughout the different parts of the study, which is outlined in the following.

I adopt the definitions provided by Crotty (1998, p. 3): 'Methods: the techniques or procedures used to gather and analyse data related to some research question or hypothesis. Methodology: the strategy, plan of action, process or design lying behind the choice and use of particular methods and linking the choice and use of methods to desired outcome'.

3.1 Ontological and epistemological assumptions and research paradigms

Since a researcher's ontological and epistemological assumptions shape the research carried out (Crotty, 1998; Saunders *et al.*, 2016; Creswell, 2014), I explain my stance in these matters in the following section. Ontology concerns the way we look at the world and how we perceive 'the nature of reality' (Saunders *et al*., 2016, p. 127), whereas epistemological assumption has to do with how we consider knowledge of the world to be obtained: 'how we know what we know' (Crotty 1998, p. 8).

Ontological assumptions have been labelled as either subjectivist or objectivist (Saunders *et al*., 2016). In management research, subjectivists considers the nature of an organisation to be the sum of its individuals, while objectivists considers an organisation to be an independent whole. However, the two - subjectivism and objectivism - should not be considered as distinct concepts but rather as two extremes, according to Saunders *et al*. (2016). Other researchers see them as distinct concepts but offer an in-between concept also, where organisations are studied in terms of both individuals and organisations with their structures, processes and environments - namely, using the 'systems approach' (Reihlen *et al*., 2007). I am an in-between researcher, leaning towards subjectivism. I, for instance, believe that an organisation cannot act on its own and that interactions between organisational entities rely on interactions between individuals. This gives me a strong focus on individuals rather than on organisations, which is reflected in the methods selected for this thesis.

With respect to epistemological assumptions, they also can be discussed as two extremes which according to Bryman and Bell (2015) can be labelled Positivism and interpretivism. Individual authors name the extremes differently, as an example do Saunders *et. al* (2016) use the terms objectivism and subjectivism. Definitions of the extremes remain that one extreme rely on objective, measurable and sensed facts, whilst the other considers knowledge to be subjective, interpreted and include opinion (Saunders *et al.* 2016). I am a researcher believing that knowledge is subjective and open to interpretation. It is never unbiased and can not be separated from the knowing person (Hislop *et al*., 2018).

3.1.1 Research paradigm

Naturally, the concepts of ontology and epistemology are closely related (Crotty, 1998) and, together, they form *worldviews* (Creswell, 2014), *paradigms* (Saunders *et al.*, 2016) or *metatheories* (Reihlen *et al.*, 2007). These concepts overlap, although they are not identical, which is reflected in differences in terminology (Creswell, 2014). In this thesis, I use the term 'research paradigms', presented by Saunders *et al.* (2016).

Saunders *et al*. (2016) differentiate between the five research paradigms that tie ontology, epistemology and methodology together. A simplified version of Saunders' paradigms is provided by Koch-Ørvad (2019), where three paradigms are presented, which are of special relevance to management studies (see Table 2). Since this thesis builds on the research fields of facilities management, construction management, project management and knowledge management, they are also considered here. Only the latter, knowledge management, is presented in the theoretical background because the others relate more to the empirical context.

Table 2 Overview of relevant research paradigms (Koch-Ørvad, 2019, based on Saunders et al. 2009)

Paradigm	**Ontology** *Nature of reality*	**Epistemology** *What constitutes acceptable knowledge*	**Methodology** *Data collection techniques often used*
Positivism	Objectivism *Objectives studied are independent of the observer*	The truth can be discovered through observed phenomena	Quantitative methods *Statistical, experimental, measurements*
Interpretivism	Subjectivism *Objectives studied are dependent on the observer*	Focus on differences between humans in our role as social actors	Qualitative methods *In-depth investigations, grounded theory approach*
Pragmatism	Pluralism *The ontological view is selected to best enable answering the research question*	Focus on practically applied research, integrating different perspectives to help interpret the data	Mixed or multiple method designs, quantitative and qualitative

During my three-year research project, I moved from pragmatism to interpretivism. Initially motivated by my own struggles with integrating operational knowledge into construction projects, I set off to investigate the phenomenon with the aim to develop recommendations for practice, preferably in the form of a guidebook or, at least, to lay the foundations for a guidebook. It would be reasonable to accuse me of aiming to assist my own future practice. Thus, a strong personal motivation (Maxwell, 2008) was the starting point of this study. I was, as is evident in the earliest paper (Paper A), devoted to investigating the tools and methods used to transfer knowledge. Later on, I also focused on whether any tools and methods from the practice of ship design could be transferred to the practice of building design (Paper E). As my study proceeded, I first became aware that, as a researcher, I was seeing things through my prior knowledge and experience (Schwartz-Shea *et al*., 2012) and then, based on the collected data, that the use of tools and method depended on the individuals rather than on the tool itself or on the organisation in which it was used. Therefore, the paradigms used for the later steps of my study are closer to interpretivism (Saunders *et al*., 2016; Schwartz-Shea and Yanow, 2012). Furthermore, the focus of my research changed from looking at what buildings and ships can learn from one another (e.g. a specific tool), as I did in the beginning, to looking at what can be learned about the integration of operational knowledge into design by comparing the two.

3.1.2 Qualitative multi-method study and not mixed-method study

Research can be qualitative, quantitative or a combination of the two - employing the so-called mixed-method approach (Creswell, 2014). As Papers A and D both include questionnaire surveys, the logical conclusion is that the approach must be a mixed-method one. However, qualitative and quantitative should not be interpreted as two distinct categories but rather as two extremes along the same continuum. As Creswell states: 'A study *tends* to be more qualitative or vice versa. Mixed-method research resides in the middle of this continuum because it incorporates elements of both qualitative and quantitative approaches' (2014, p. 3). As the greatest portion of this PhD study rests on a qualitative research approach, I consider it to be qualitative. However, I also supplemented my qualitative research with sub-studies that have quantitative characteristics when I found that they added insights to the overall study. Step 4, described in Paper D, provides an example of how I applied a quantitative approach (questionnaire survey) to gain further knowledge from the findings obtained in a study based on a qualitative approach (steps 2 (partly) and 3), described in Paper D.

The case study method was chosen because the purpose of my research was to understand *how* rather than *what* or *how many* (Yin, 2014). I investigated a context-dependent topic (Flyvbjerg, 2006) of knowledge integration into design processes, which cannot be moved to a laboratory and thus needs to be studied in its natural setting (Creswell, 2014).

3.2 Sequential research methods

The stepwise design of my studies served two purposes. First, as mentioned, the purpose was to allow one step to inform and influence the following ones. Second, it also served a purpose more closely related to project management, where a large three-year research project was split into sub-studies with individual time schedules, resources and goals to make the project more manageable. As is typical of construction projects, the decisions made in one step of my study influenced the following steps taken and, even if it had been possible, it would not have been desirable to conduct all the steps simultaneously by five individual researchers, for instance. Examples of how different steps shaped the subsequent ones are provided later.

The steps are described and listed below as well as illustrated in Figure 5. They are:

1. Literature review, parts l and ll. Part one presents a systematic review, while part ll focuses on the theory relevant for a certain part of the study (abduction), applying a snowball technique.
2. Expert interviews. Considered to be a method on its own (Froschauer and Lueger, 2009), unattached to any case.
3. Focus group interviews and workshops. This step resulted from a change of plan and it informed and validated certain findings from the expert interviews conducted in step 2.
4. Survey. A web-based questionnaire that aimed to add specific examples and gain further empirical knowledge on the findings obtained from steps 2 and 3.
5. Multiple case study. Three ship cases and two building cases.

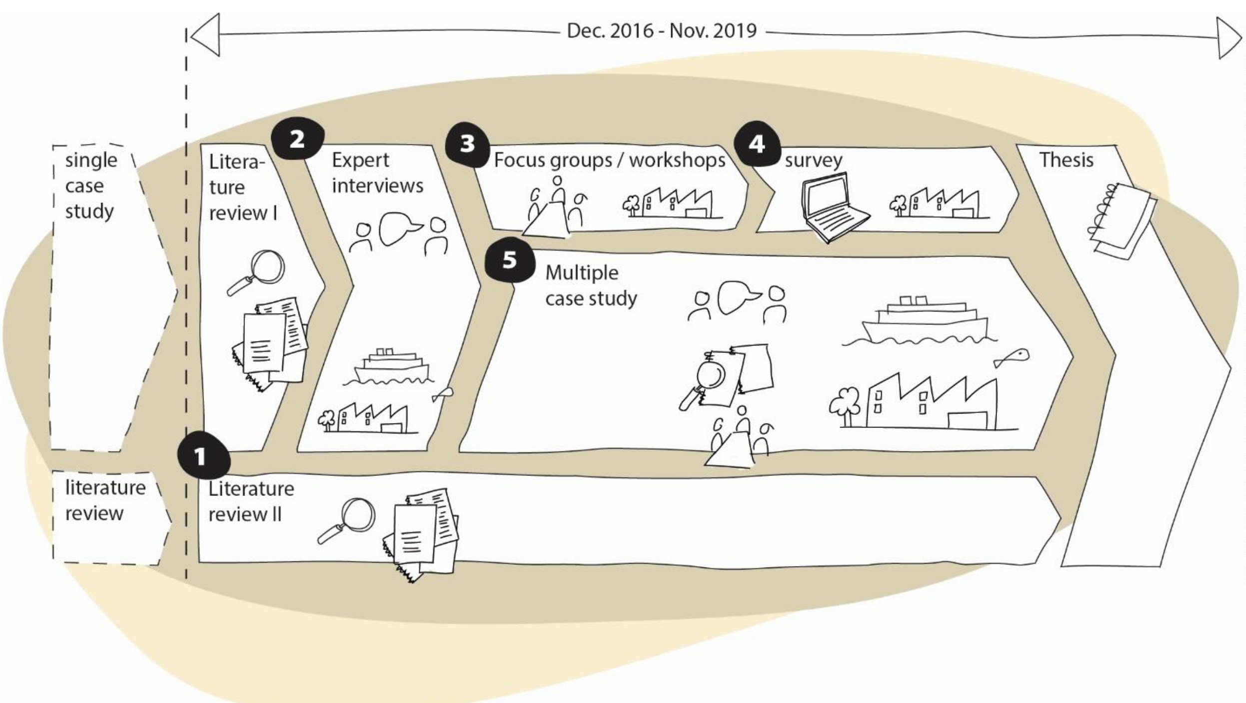

Figure 5 Research method steps.

In addition to the five main steps, additional sub-studies were carried out:

- Single case study (data collected prior to the PhD study, Paper A).
- Data collected by others, prior to the PhD study, through a survey (Paper A) and a single case study (Paper B).
- Data collected as part as the PhD study but not included in any papers disseminated (Sweco stay and five interviews).

3.2.1 Abductive study

The overall research approach was abductive (Alvesson and Sköldberg, 2009; Schwartz-Shea and Yanow, 2012), although some sub-studies and papers employed an inductive approach. The study had its starting point in a puzzle (for me, personally, see preface) and went back and forth from different sources to gain knowledge, using a combination of the knowledge gained from different sources to increase knowledge generation. Typically, abduction is defined as going back and forth from the empirical context to the theoretical one (Saunders *et al.*, 2016). However, it can also refer to the shift between the empirical contexts (Schwartz-Shea and Yanow, 2012). In this study, it indicates both. The spiral shown in Figure 6 illustrates how I moved across the steps, while moving forward in a way that can best be described by a quote from Schwartz-Shea and Yanow (2012, p. 27): 'Abductive reasoning begins with a puzzle, a surprise, or a tension…In this puzzling out process, the researcher tacks continually, constantly, back and forth in an iterative-recursive fashion between what is puzzling and possible explanations for it, whether in other field situations…or in research-relevant literature. The forth and back takes place less as a series of discrete steps than it does in the same moment: In some sense, the researcher is simultaneously puzzling over empirical materials and theoretical literatures'.

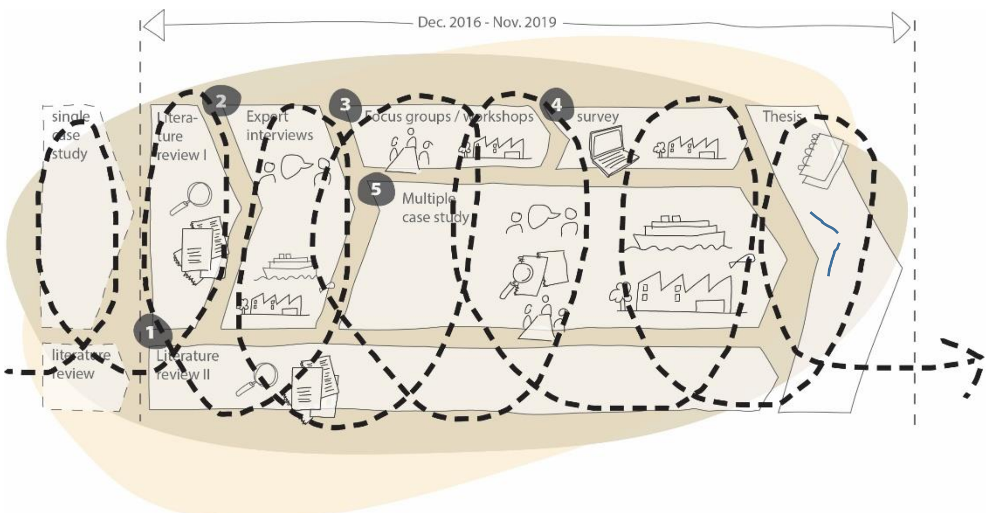

Figure 6 The spiral represents the hermeneutic spiral, illustrating an abductive approach.

3.3 The five steps

This section describes the five steps conducted for this study, with the aim of providing an overview of the PhD work, seeking to account for how the steps were carried out and how they shaped the following ones. This means, unfortunately, that some repetition of the material presented in the individual papers will occur. The section starts with an example of how the method steps were altered in the process. Then, the steps are described one by one in section 3.3.2-3.3.7.

The papers do not completely follow the steps because they draw on more than one step - as illustrated in Figure 7 and listed in Table 3.

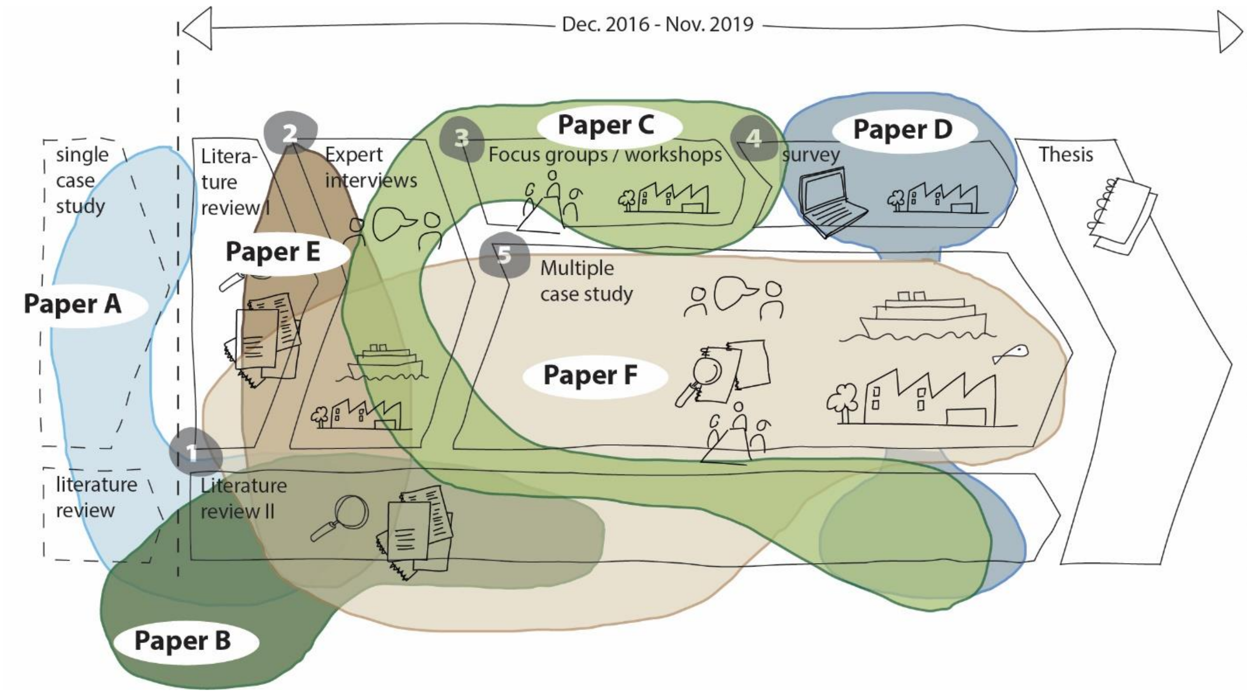

Figure 7 Relations between method steps and papers.

Table 3 Empirical method steps and their applications in the papers.

Overview of the applied empirical methods- executed by me								
Method	**Industry**	**Data**	**A**	**B**	**C**	**D**	**E**	**F**
Single case study	Building	1 interview 2 focus group interviews Documents	x					
Expert interviews - Ships	Ship	6 interviews					x	x
Expert interviews - Buildings	Building	4 interviews			x			x
Focus group interviews and workshops	Building	2 focus group interviews 3 workshops			x			
Survey	Building	Self-administered questionnaire				x		
Multiple case study	Ships (3) Buildings (2)	11 interviews 5 focus group interviews Documents 2 meeting observations						x
Additional interviews	Building	5 interviews						
3-month stay at the Sweco A/S office	Building	Diary notes						

3.3.1 Change of plans: Performance gaps and FM difficulties

In line with the interpretive research approach, my investigation began ‘where the light is’ (Schwartz-Shea and Yanow, 2012), as illustrated in Figure 8. The beginning was based on the focus found in the literature by investigating existing tools and methods. As my study proceeded, performance gaps showed themselves to be important in terms of how operational knowledge is integrated into design processes. I found, on the one hand, that the literature on performance gaps was entirely occupied with the energy performance gap. On the other hand, I found literature on difficulties in operation fragmented and scattered across many research fields. Concerning performance gaps, the experts I interviewed during step 2 were occupied with many other gaps, which they explicitly pointed out to me. I wondered whether this was important for gaining a deeper understanding of how operational knowledge is integrated into design and I consequently decided to take a ‘detour’ off the path that I had initially laid out for my study. Hence, I recoded the interviews conducted in step 2 (expert interviews), collected further data and added an additional validation step (step 3). Concerning the fragmented literature on difficulties in operation, I conducted a simple questionnaire survey (Step 4) in cooperation with one of my funding partners, Sweco A/S. The aim was to gather and categorize difficulties experienced by facilities managers in new buildings in Denmark.

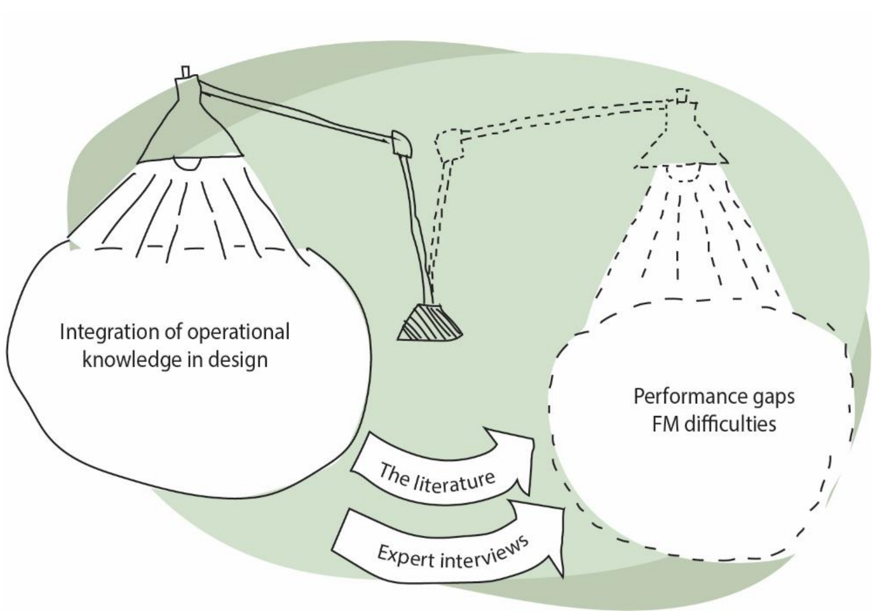

Figure 8 Expansion of the research focus.

3.3.2 Data collected prior to the PhD study

Data for Papers A and B were collected before my PhD project began. I collected the data for the Paper A (single case study) as part of my post-graduate master’s degree. The questionnaire survey on swimming facilities, also found in Paper A, was conducted by one of the other authors as part of his master’s thesis. Further analysis and development of this journal paper were performed as part of my

PhD study. Data collection for Paper B was made by one of the co-authors as part of her master's thesis. I contributed to further analysis, theoretical background, discussion and conclusion sections of the paper as part of my PhD study. Only the data I collected myself are described here. For more details about the data collected by others, please see papers A and B.

As mentioned, I conducted a single case study for Paper A. DTU Campus Service was selected to be the case because they represented an extreme one (Yin, 2014) because they had deliberately worked on improving the integration of operational knowledge into design. They had a large internal operation division and they expressed high ambitions for benefitting from this when expanding the Campus Site with several new buildings. This made the case particularly interesting: They had the knowledge, they acknowledged the value of reusing it and they had worked on this for several years already; thus, I made the assumption that they could serve as inspiration to others.

The DTU Campus Service single case study was different from the case studies conducted in step 5 because the unit of investigation (Yin, 2014) was an organisation and the procedures, tools and methods identified here were not linked to a specific project. This provided insights into various tools and methods but made it difficult to know whether, for instance, a tool was used consistently in every new project and how certain project differences, such as tender strategy and project manager competence, influenced the use of tools and methods. Hence, the case studies conducted later on (step 5) focused on specific building or ship projects as their unit of investigation.

3.3.3 Step 1: Literature review I and II

This step was split into two separate method steps, as illustrated in Figure 5.

The first part of the literature review was a systematic review and followed a stepwise method (Okoli and Schabram, 2010; Nielsen *et al.*, 2016) to establish the state of the art of the literature on integration of operational knowledge into design and to identify the existing tools and methods for integrating operational knowledge into design. Furthermore, this method was useful for identifying what underlying theoretical approaches are used by researchers to shed light on knowledge transfer from operation to design.

As such, the systematic literature review aimed at answering the question 'What is out there in the literature?' Supplementing the search by Boolean operators (Okoli and Schabram, 2010), the search for relevant literature included searching both backwards and forwards for relevant papers on the topic (Webster and Watson, 2002; Nardelli, 2015). This part of the literature review served as a basis for the second step.

The second part of the literature review included a much broader review of relevant theory. It served as a basis for several subsequent parts of the research study, as illustrated in Figure 5, and was carried out for the duration of the entire project and included searching backwards and forwards (Webster and Watson, 2002; Nardelli, 2015). Such a continuous literature review contributed to the project with examples from the literature that were mainly within the fields of knowledge management, knowledge transfer, facilities management, construction management and performance gaps.

The systematic literature review (review I)

Boolean operators were applied to the search for relevant papers in the systematic review. Search terms included *knowledge* (or *know how*), *transfer* (or *sharing, feed back, management, integration*), *building operation* (or *operation and maintenance, facilities management, facility management, FM*) and *building design* (or *construction, hand over, design*). The search resulted after an initial screening in 93 scientific journal papers. A second screening was conducted based on title, keywords and abstract of the 93 articles and resulted in eight relevant paper. The majority of the 93 papers was excluded because they concerned knowledge transfer from project to operation, thus the 'opposite direction' of what I was looking for in the search. Three papers were added by backward and forward search, thus the search resulted in 11 papers of relevance for my research.

The systematic literature review on knowledge transfer from operation to design of buildings was published as a conference paper (Rasmussen *et al.*, 2017). The paper itself is not included in this thesis because the literature review it presents has since then been heavily extended by the broader review on literature (review II) on integration of operational knowledge in design conducted over the three-year study period.

Similarly, I began to conduct a systematic review on the integration of operational knowledge into ship design. The search results were limited to a few papers, indicating that it did not make much sense to continue with the subsequent steps of the review. The limited results possibly resulted from faulty terminology. However, researchers in the field of ship operation and design whom I discussed my limited search results with confirmed that the topic was under-researched.

Limitations to the systematic literature review

The search resulted in a limited number of papers of relevance to my study. As I later found from the second and broader literature review, the terminology concerning integration of operational knowledge into design is far more diverse than I had first assumed. Thus, the systematic review gave insight into the underlying theoretical assumptions (behavioural and technocratic) and revealed that the opposite direction of transfer (from project to operation) is more researched (Rasmussen *et al.*, 2017). However, the search results were insufficient in terms of establishing the state of the art of literature on the topic. If I were to do it again, knowing what I know today, my Boolean operators would have been formulated differently, including a much larger variety of terms, and much effort would have gone into searching forward to include the most recent research, too. The fact that my search for papers on the topic of integration of operational knowledge in ship projects only resulted in few papers is possibly also partly caused by the faulty use of terminology. Conducting the following broader literature review, which followed a snow-ball methodology rather than search terms intended to make up for the limitations of the initial literature review.

3.3.4 Step 2: Expert interviews

I consider expert interviews, where relevant experts are interviewed independent of a case, to constitute a method on its own (Froschauer and Lueger, 2009). Applying this method to step 2 aimed to provide the 'state of the art' of concepts, initiatives and tools used by practitioners, answering the question 'What is out there in practice?' The experts were practitioners involved in new ship or new building projects, mostly in Denmark. The data collection technique used was semi-structured interviews (Saunders *et al*., 2016). The ATLAS.ti software was used for the coding and analysis.

Additionally, the study served as a step 5 pre-study, providing knowledge about the ship industry of which I had limited prior knowledge. Possible cases for step 3 were explored with the interviewees and, thus, my network within the ship building industry was established, although it remained limited in size in comparison to the one I have for the building industry.

Selection of interviewees

As described in Paper E, the interviewees were identified using a snowball sampling technique (Saunders *et al.*, 2016; Bryman and Bell, 2015), where interviewee 1, for instance, suggested other people who would be of relevance to the study. From these suggestions, I selected additional interviewees to provide maximum variation (Bryman and Bell, 2015). Saturation (Bryman and Bell, 2015) appeared after the sixth ship industry interview and, even though I did conduct a seventh short ship industry interview, I did not transcribe nor analyse it and it is not listed here. Saturation appeared after only four building industry interviews, which I speculate was due to my prior knowledge. To exploit further interviews, I could have changed my interview guide and the themes I was investigating. However, as I found that the expert interview method had its limitations, I decided not to conduct further expert interviews in order to allow for sufficient time to execute subsequent method steps.

A short description of the 10 interviewees and their relevance to this study is provided in Table 4. The focus of the study was to identify the tools and methods to enable integration of operational knowledge in design. Previous research has identified the building clients' representatives to implement such tools and methods. On the other hand, those who should take action in terms of using the tools, for instance LCC tools in the design process are primarily members of the design team. Thus, interviewees belonged to both the client and the design team sides.

Table 4 Experts interviewed in step 2; a simpler table is included in Paper F.

Role	No.	Interviewee	Relevance to the study	Duration
Ship designers	1	Naval architect, self-employed consultant.	Experienced ship project designer for many ship types, including ferries and military ships.	58 min.
	2	Industrial designer, self-employed consultant.	Experienced ship designer. Known for focusing on aesthetics in ship design, including large yachts and military ships.	77 min.
	3	Naval architect, owner of a ship design company.	Experienced in designing and managing many types of large ship projects, including ferries and large cruise ships, for both public and private customers. His ship design company includes an interior design department.	76 min.
Ship owners **(clients)**	4	Former head of a new ship division at shipping company; now the head of a research centre.	Experienced representative of a client who builds to occupy. Known for his revolutionary approach to ship design, which include iterative steps of designing to improve ship performance. Primarily experienced in cargo ship design but has earlier experience with large cruise ships also.	66 min.
	5	Head of a new ship division at a shipping company.	Experienced as head of project managers for new ship projects and of site inspectors. Experienced with all stages of building projects. Primarily cargo ships.	57 min.
	6	Head of a new ship division at a shipping company.	Has many years of experience as a head of project managers for new ship projects and of construction site inspectors. Experienced with every stage of building projects. Primarily cargo ships and ferries.	34 min.
Building designers	7	Building client consultant, self-employed.	Experienced project manager for large and complex building projects. Known for focusing on integration of operational knowledge in design.	64 min.
	8	Architect, owner of architectural firm.	Experienced in all stages of building projects, primarily large non-residential projects. Known for focusing on sustainability.	49 min.
Building owners **(clients)**	9	Director of a technique and environment division at a real estate and property investment company.	Experienced top manager for both building project divisions and operation divisions. Builds to occupy. Known for his involvement in the Danish 'Building Green' organisation.	53 min.
	10	Former project manager in a new building division for a large private company; now a self-employed building client consultant.	Experienced project manager for large complex building projects in an organisation with an internal operational division. 'Builds to occupy'.	50 min

Analysis of the expert interviews

The expert interviews were used in three papers - five of the ship interviews are included in Paper E, four building interviews are included in Paper C and all ten interviews are included in Paper F, as illustrated in Figure 7 and Table 3. The papers have different purposes and answers different research questions (for an overview, see Table 1); thus, the interviews were analysed differently.

Common for their analysis is the fact that I transcribed all ten audio-recorded interviews and imported their transcripts into ATLAS.ti. For the purpose of Paper E, a thematic analysis (Bryman and Bell, 2015) was employed, where themes were partly developed from the literature (including Paper A), which also informed the interview guide, and partly emerged from the field. For the purpose of Paper C, an approach to analysis that is closer to the grounded theory (Bryman and Bell, 2015) was employed, although it was limited to the four building interviews. In Paper F, a thematic analysis was employed again, with some reuse of codes from the initial coding for the purpose of Paper E. However, the themes that emerged from the multiple case study conducted later (step 5) were explored here as well.

Limitations of the expert interview method

The expert interviews resulted in valuable insights and were relevant for more papers, answering different research questions. However, the method also had limitations. First, as described in Paper E, transfer of knowledge is a rather abstract topic that is difficult to discuss in great depth during a one-hour interview. That means that, on the one hand, it is quite possible for the interviewees not to have mentioned some tools and methods simply because they never thought of them as tools or methods to transfer knowledge. On the other hand, they knew my research topic and that I considered the integration of operational knowledge into design important and the 'right thing' to do. As people, in general, wish themselves and their organisations to appear to be doing the right thing (Alvesson, 2011), there is also a risk that they could have exaggerated how well the tools were implemented and their benefits or they could have understated the obstacles.

3.3.5 Step 3: Focus groups and workshops

The third step, focus groups and workshops, served to further develop and validate an initial performance gap typology, which were derived from the expert interviews of the previous step. The step consisted of two elements: first, two focus group interviews were conducted (Kevern and Webb, 2001; Bryman and Bell, 2015) and, second, three workshops were organised (Ørngreen and Levinsen, 2017). The focus group interviews aimed at getting further insights on practitioner's experience with types of performance gaps. The initial typology was presented to the groups. Following, they were asked to discuss and if necessary supplement with additional types of performance gaps they found relevant. This resulted in further development of the typology by identifying four additional types. The workshops were slightly different. Here, the participant were asked to solve two small tasks together based on the typology. The purpose of the workshops were to validate as well as disseminate the typology. The method is described in more detail in Paper C and a brief description of the interviewees is provided in Table 5.

Table 5 Focus groups interviewees and workshop participants

Technique	No.	Interviewees/Participants	Relevance to the study	Duration
Focus groups	1	2 associate professors at the Copenhagen School of Marine Engineers 2 FM consultants (advisory board)	Experienced with FM.	60 min.
	2	3 interviewees 2 FM consultants 1 Commissioning expert	Experienced with FM and trouble shooting in completed buildings.	60 min.
Workshops	1	2 FM consultants (same as Focus group 2)	Experienced with FM and trouble shooting in completed buildings.	60 min.
	2	3 FM researchers	Hold knowledge on FM, design and construction projects.	90 min.
	3	5 FM staff members at Campus Service, DTU	Experienced with project management of building projects (2). Experienced with trouble shooting in completed buildings (1). Experienced with FM (2).	90 min.

Limitations to the focus group interviews and workshops

As for any method, both the focus group interviews and workshops had limitations, a few are mentioned here. First, the number of interviewees and workshop participants were limited. Moreover, did a few persons participate more than once. This was a question of both accessibility (Alvesson, 2011) and time limitations. Furthermore, interviews are artificial situations (Alvesson, 2011) and presenting preliminary findings as an introduction to both focus group interviews and workshops narrowed rather than broadened the participants' discussion (Alvesson, 2011).

3.3.6 Step 4: Questionnaire survey

The purpose of the method step 4 was to further explore the findings obtained from steps 2 and 3, regarding performance gaps (Paper C). While the practitioner's to whom I presented the typology found it interesting, they also thought it to be too abstract and too broad to add value to their daily work. I could see what they meant and, as a result, I teamed up with one of the Sweco A/S FM department staff members, with whom I shared an office every Monday at that time, to conduct a questionnaire survey (Burns *et al.*, 2008).

The aim of the survey was to obtain a 'catalogue' of specific FM difficulties in newly built facilities in Denmark and, furthermore, to get an indication as to which of these difficulties were interpreted as 'most experienced' by the respondents.

The sub-study followed two steps. First, concrete difficulties, of which there ended up being 35, were identified. This was done by consulting the literature and asking a group of practitioners and individuals to identify the difficulties they had experienced. Thus, 35 difficulties in total were listed, spread among 6 categories. Second, a web-based self-administered questionnaire was distributed among FM practitioners in newly built facilities in Denmark (see Paper D for further description of the survey questionnaire).

The study of FM difficulties received a great deal of interest from practitioners. The co-author and I were invited to present the findings on several occasions (see List of presentations in the appendices). Two presentations were given at FM organisations belonging to two large Danish universities, who build and operate university facilities. Since the survey had limitations (described in Paper D), I recognised the invitations to give presentations as a good way to supplement the quantitative survey with qualitative semi-structured interviews. Thus, I invented the concept of 'black-mail' sampling. I simply asked for three in-depth interviews with my choice of staff members from these organisations in return for a presentation. To my surprise, they found that to be a very reasonable price. Consequently, I conducted five semi-structured interviews to further inform the survey results. However, I soon realised that I was jeopardising my overall time schedule and moved on to step 5, multiple case study. As a result, I collected more data than I had time to use in the papers.

Limitations of the survey method

A self-administered questionnaire is definitely not free of limitations.

First, the questionnaire was kept short to increase numbers of respondents. Unfortunately, the background questions were too limited and resulted in 29 completed questionnaires were omitted from the results. Second, the number of respondents was low. Moreover, as the respondents are anonymous, it is impossible to know if more respondents describe difficulties in the same new building.

Third, the results indicated that less difficulties were experienced concerning e.g. interior design and architecture in relation to brand and culture of the enterprise. No information on area of responsibility, educational background or personal interests were included in the questionnaire. Thus, it remains unanswered if this result simply reflect that the respondents are not handling difficulties on interior design and architecture on a daily basis.

The questionnaire examined which difficulties were most and least often experienced by the respondents. It did not give any answers to which difficulties respondents considered to be most important or which difficulties have the most negative consequences.

3.3.7 Step 5: Multiple case study of design process of new ships and new buildings

Step 5 - the multiple case study - is described in Paper F and includes a brief introduction to the cases. To avoid repetition, the issues described in Paper F are either only briefly mentioned here or not are not mentioned at all.

A case study protocol (Yin, 2014) was developed as the first case study step. It described the purpose and research question for it, the criteria for case selection, the unit of analysis, the data collection techniques, the initial theoretical background ideas and themes to be investigated as well as the time schedule. Unlike the DTU Campus Service case study described in Paper A (conducted by me) and the one in Paper B (conducted by a co-author), the unit of analysis of the cases in method step 5 was the design process (with delimitations described in section 1.3) of a specific project of a new building or large ship.

Emerging case selection

This multiple case study consisted of five individually investigated cases (Yin, 2014): three ship projects and two building projects. Like the entire three-year research study, these five case studies were done in a sequential manner. Thus, one case was first selected and its data collection was initiated before the subsequent case was selected. The first case can be viewed as a pilot case study that was included in the study equivalent to the others. Moreover, I wanted not only the first case study to shape the subsequent ones but also to achieve the opposite - ensuring that it was possible to go back to the incomplete first case to investigate the themes that showed themselves to be important in case 2 or case 3, for instance. There was an intended overlap in time between the cases (which made some of their timelines more parallel than sequential), mostly due to time constraints.

Due to the fact that building and large ship projects span over a longer period of time than what I had allocated to this method step, I selected cases that were at different stages - design, construction and operation. The three ship cases were in the stages of design (case 2), construction (case 1) and operation (case 3). The two building cases were in the stages of design (case 5) and operation (case 4).

Cases in the design stage made it possible to perform observations and had the advantage of their participants having a 'fresh memory'. The disadvantages included the fact that I could not gather an overall picture of the process and all the tools and methods used because the design process was incomplete. Cases in the construction stage had the advantage of offering me the possibility of gathering a more complete overview, while the memories of the participants were also still fresh. The disadvantage was that it was not possible to perform observations. Completed cases, which were recently handed over, had the advantage that all their participants could reflect on how various initiatives had influenced facility performance. Furthermore, they reflected how actions in the construction and handover stage threatened performance regardless of efforts made to ensure the integration of operational knowledge during the design stage. The disadvantages included the fact that the interviewees may have forgotten certain details and that they tended to focus more on the last stage, the construction stage, than on the design stage that was completed a long time ago.

Case selection criteria for a multiple case study

The case protocol included a strategy for selecting cases. All cases were selected to be 'good examples' or, at least, to be cases in which I was certain to find some initiatives towards integrating operational knowledge. With respect to building cases, my advisory board and I knew several cases in which the building client had done a lot to integrate operational knowledge into design. We knew this from media, from our networks and from looking through Sweco's projects. On the contrary, detecting such cases concerning ships was harder. Lacking a personal network, I called one of the interviewees from the expert interview step. He was well-informed about ferry projects in Denmark and had several suggestions about both ongoing and recently completed cases that I could choose from. I looked into all the suggested building and ship cases and selected two of each based on a list of criteria (see below), accessibility and timing. The fifth case (a ship case) was selected based on suggestions from an interviewee in case 1. The interviewee mentioned this case as an interesting case in regards of this research as he considered it to be a good example of the integration of operational knowledge in ship design. As I later decided to add a third ferry case, I returned to his suggestion.

The selection criteria were developed based on: 1) Ensuring a certain similarity across cases to ease comparison, 2) Literal sampling predicting similar results and 3) Theoretical sampling, predicting contrasting results (Yin, 2014).

The case selection criteria for both building and ship projects were:

- ‘Build to occupy’ clients;
- Ambitious goals for sustainability/energy efficiency;
- One public and one private client;
- Cases with a completed design stage and with an ongoing design stage;
- For practical reasons: A building client/design office in Denmark or nearby;
- Medium-size project.

Additional criterion for buildings:

- Non-residential.

Additional criterion for ships:

- Passenger ferry.

Ferries were chosen over cargo ships to increase similarity with building cases. Ferries, like the selected buildings, have a ‘third’ actor/user-e.g. customers, patients and travellers. Moreover, I assumed that they would also be interested in aesthetics and user experience. Finally, ferries were accessible and had a ‘manageable’ size in contrast to large cruise ships.

I included ‘Ambitious goals for sustainability’ as a criteria based on the assumption that a sustainability agenda is a driver for integrating operational knowledge into design and, consequently, would lead me to ‘good examples’. Furthermore, non-residential buildings were chosen to ensure that there was an operational organisation to involve.

As mentioned, I also added an extra ship case when I realised that whether a new building or ship was designed to fit into a larger portfolio or not plays an important role. The two ferries that were first selected were both ‘stand-alone’ ships and I added a third ship case. This forced me to limit the data collection for ship cases 2 and 3 (the additional case) due to time constraints.

Table 6 describes basic information about the selected cases. It comes from Paper F.

Table 6 Basic information about the cases, Paper F.

Industry	**Ships**			**Buildings**	
Case	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**
Project	Passenger and car ferry	Passenger and car ferry	Passenger and car ferry	Airport extension	Hospital building
Client	Private	Public	Private	Private	Public
Budget (Capex)	8.5 million Euros	36.2 million Euros	67 million Euros	60 million Euros	80.5 million Euros
Standalone facility or part of portfolio	Single	Single	Portfolio	Portfolio	Portfolio
Stage when studied	Construction	Design	Operation	Operation	Design
Data collection	4 interviews Documents	2 interviews Documents	1 interview Documents	4 interviews Documents	3 interviews Documents Observations

Data collection in a multiple case study

I collected data for the case studies over a period of 10 months from August 2018 to May 2019. To compensate for my limited prior knowledge on ferry projects, I started with a ferry case. I wrote an individual case report for each case, which I then used for a comparison across cases.

Data collection techniques (for multiple case study):

- Archival documentation (meeting minutes, review protocols, briefs, procedures, etc.), as described in Table 7;
- Semi-structured interviews (single and group, face-to-face and phone/Skype), as described in Table 8;
- Meeting observations (limited to two), as described in Table 9.

In the following section, data collection techniques are briefly presented. Besides the listed documentation, interviews and meeting observations, a supplementary internet information search was conducted, including that of the homepages of the owners and designers. Moreover, e-mail correspondence - concerning participation in the research project, date and location of interviews, follow up questions, report comments and matters of confidentiality - took place but the details are not listed as data.

Archival documentation:

I collected archival documentation, listed in Table 7, to supplement the data collection and as preparation for the interviews when possible. This gave me the opportunity to check for certain conditions or methods in the design process that the interviewees perhaps did not think were relevant for my study and therefore did not mention. Finally, it also provided basic information about the cases, which I could then ask my interviewees to confirm.

Table 7 Archival data collected for the multiple case study

Case	Archival documentation	Relevance to the study
Case 1 Passenger and car ferry	Board meeting minutes, 2017 and 2018.	The board collectively managed the project and acted as a steering committee. The minutes described decisions made regarding the project, including design and design process.
	Budget, capex and opex.	Five-year operations budget (opex), two-year detailed operations budget (detailed opex) and the project budget (capex) in the same spreadsheet.
	Tender letter to shipyards.	The tender included design and construction details.
	General arrangement.	Drawings 1:200 of the project.
Case 2 Passenger and car ferry	Tender documents to shipyards.	A total of 23 documents describing the design and the specifications of the new ferry. Downloaded from the ferry owners homepage (13 August 2018), publicly accessible.
	Presentation slides: 'Decisions and tender process'.	Described the process in headlines, including the involvement of interest groups and time schedule. Downloaded from the ferry owners homepage (13 August 2018), publicly accessible.
	Presentation slides: 'New ferry'.	The tender included design and construction.
	Board meeting minutes 2017-2018.	Described the tender process and political discussions, including discussion on alternative design proposals. Downloaded from the ferry owners homepage (13 August 2018), publicly accessible.
	Web page.	Described the organisation of the ferry owner, including ownership and board. Downloaded from the ferry owners homepage (13 August 2018), publicly accessible.
Case 3 Passenger and car ferry	Article in the Maritime publication 'Søfart'.	An article describing the design concept, including energy efficiency, speed and capacity of the new ferry.
	Article in the member magazine of the Marine Engineers Association.	An article describing the handover process and early operation (maiden voyage) of the new ferry.
Case 4 Airport extension	Building brief.	Detailed brief describing the initial design and specifications of the new building.
	Interface description.	Document describing parallel tender and design processes and responsibilities.
	Risk analysis description.	Document describing risk analysis.
	Review documentation.	Spreadsheets documenting the reviews (comments and questions) given by operational staff in two design stages and the design team's replies.
Case 5 Hospital building	'Playbook' for the project.	Described visions for the project, including the societal and medical goals for the new centre.
	Time schedule.	Included the major design steps, such as involvement of clinical staff and operational staff.
	Initial design proposal.	Provided descriptions and drawings of the initial design, including an 'executive summary'.
	Minutes and appendices from meeting with clinical staff.	Minutes from the meeting which I observed, see Table 9.

Semi-structured interviews:

As in many case studies, interviews were the main source of data generation in this case study (Yin, 2014). All interviews were semi-structured and based on an interview guide (Saunders *et al*., 2016). The guide was developed based on previous steps of the study: the literature review (step 1) and the expert interviews (step 2). The guide included questions on the general condition (see Paper E) of the project and questions aiming at identifying the specific tools and methods for integrating operational knowledge. The interview guide was developed throughout the study. In cases in which more than one interview was conducted, the interview guide for additional interviews was changed to investigate certain aspects in more detail or to get a different view on the same topic. For example, I had the first interviewee in one ship and one building case outline the design process (see Figure 9, photos) but, because it was time consuming, I left that out when conducting additional interviews for the same cases. Table 8 provides a list of interviews included in the multiple case study.

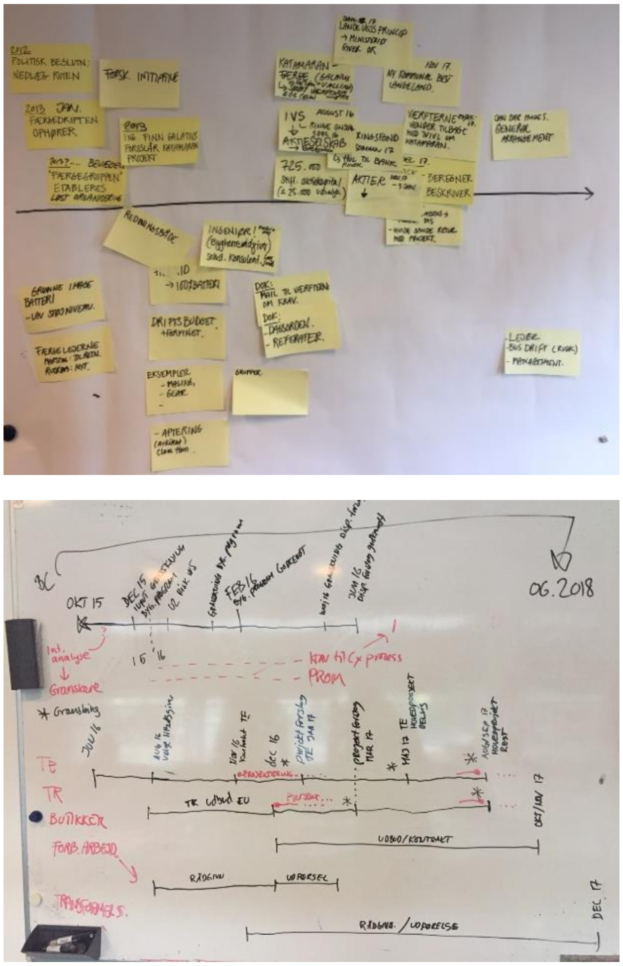

Figure 9 Photos from two focus group interviews.

Table 8 Interviews conducted as part of the multiple case study

Case	Role	No.	Technique	Interviewee(s)	Relevance to the study	Duration
Case 1 Passenger and car ferry	Client	1	Phone	Manager of the ferry company	Top manager, board member and one of several project managers.	60 min.
	Client	2	Face-to-face Focus group	3 board members, including the director of the company	The board members shared project management of the new ferry design.	85 min.
	Technical advisor	3	Face-to-face	Self-employed consultant	Ship engineer experienced in new large ship projects, including the design process.	117 min.
	Client	4	Face-to-face Focus group	2 board members, including the manager of the company	The board members shared project management of the new ferry design.	30 min.
Case 2 Passenger and car ferry	Client	5	Phone	Manager of the ferry company	Top manager and project manager of the new ferry project.	60 min.
	Client	6	Skype	Manager of the ferry company	Top manager and project manager of the new ferry project.	62 min.
Case 3 Passenger and car ferry	Client	7	Face-to-face	Deputy director of technical operations	Project manager of the new ferry project.	72 min.
Case 4 Airport extension	Client (Operation division)	8	Face-to-face	Strategic commissioning manager	Acted as the project management's one-point-of-access to operation. Managed the process of involving operational staff in the design process, including administration of review processes.	60 min.
	Client (New building division)	9	Face-to-face Focus group	2 project managers Strategic commissioning manager	Joint focus group interview with project managers and the strategic commissioning manager.	77 min.
	Client (Operation division)	10	Face-to-face	Strategic commissioning manager	Same interviewee as interview 8, this table	44 min.
	Client (Operation division)	11	Face-to-face	Asset manager	Involved as a representative of the operation division in the design process, including reviewing the design on several levels of detail throughout the design process.	52 min.
Case 5 Hospital building	Facilitator	12	Face-to-face	External consultant	Architect and facilitator who designed and facilitated the involvement of both clinical staff and operational staff.	68 min.
	Lead designer	13	Face-to-face	Architect	Employed by the client to design the new building to a certain level of detail with assistance from internal and external design staff.	43 min.
	Project manager	14	Phone	Project manager	Project manager of the case project.	92 min.

Meeting observations (only in case 5):

Only in one case did I get the opportunity to perform observations (Yin, 2014; Saunders *et al*., 2016). I was invited to observe two meetings - one in which members from the project team were meeting the clinical staff and one in which they were meeting the operational staff. Basic information about the meetings is provided in Table 9, including their participants. Based on the delimitations of this study, I was mostly interested in meeting 1; however, since I was already there, a two hour train ride away, I decided to observe both. The two meetings were very different, which I have not had the opportunity to describe in any of the papers. Nevertheless, I did write a conference abstract and gave a presentation based solely on these two observations (see List of other publications in the appendices). Insights from meeting 1, with operational staff, were included in Paper F as part of the 'Design review by operational staff'.

Table 9 Observed meetings as part of multiple case study

Case 5 Hospital building		
Meeting	**Meeting 1:** Operational staff involvement	**Meeting 2:** Clinical staff involvement
Technique	Observation	Observation
Participants	4 operational staff: O&M (1) Cleaning (2) Hygiene (1) 1 Project secretary (user/project) 1 Project manager 2 Design team Representatives 1 external innovation consultant (me) All together: 9 (10)	13 Participants: 8 users: Doctors (4) Nurses (2) Dentist (1) Administrative staff (1) 1 Project secretary (user/project) 1 Project manager 1 Design team member 2 external innovation consultant (me) All together: 13 (14)
Relevance to the study	The purpose of the meeting was to obtain comments and suggestions from the operational staff on the design proposal, a review of the design.	The purpose of the meeting was to obtain comments and suggestions from the clinical staff on the design proposal, a review of the design. It was relevant to see whether their involvement process was different from that of operational staff.
Duration	1.51 hrs.	1.44 hrs.

Multiple case study analysis

I developed an individual descriptive case report for each of the five cases, aiming to comparing them. Furthermore, this provided me with the advantage of having the interviewees approve their own cases. For the purpose of analysing across the cases, all reports followed a similar structure. The structured was organised by themes (Bryman and Bell, 2015), which were developed from three sources: 1) the literature, 2) the findings from the previous method step (expert interviews) and 3) the data. I analysed each case individually concerning all themes, as listed in Table 10. Subsequently, I applied a cross-case synthesis (Yin, 2014). As the interview guide developed as I gained knowledge - and because I was not given access to the same archival documents in all cases - the report themes slightly differed in content and level of detail.

Table 10 Multiple case study: Themes investigated and described individually for each case. The table is an extended version of a table in Paper F (italics).

Themes investigated and described individually for each case
Project background/need
Building client/owner organisation
Public/private client/owner
Project organisation, including project manager's education and experience
Consultants and design teams
Timeline
Time pressure
Change of key staff during design stage
Tender strategy
Handling of changes in design and construction
Involvement of operational staff in the design process
List of implemented tools and methods to integrate operational knowledge into design
Description of the use of each implemented tool or method
Capex and opex
Criteria for success
Critical incidents leading to changes in design crucial to operation
Energy efficiency/sustainability
Unique design or part of series (or larger project)
Planning of handover
Expected difficulties in operation after handover
End-user involvement

Anonymity in the multiple case study

In this multiple case study, the question of anonymity was raised in regard to both the individuals in each case, as interviewees, and the entire cases themselves (Yin, 2014).

With respect to the interviewees, I discussed anonymity with each of them based on the individual case report, which included both direct and indirect descriptions of what they had told me. One interviewee preferred not to be cited in the report but found the descriptions of what she had said (in my words) to be fine. None of the interviewees asked for anonymity.

With respect to the entire cases, I asked my contact persons, who were project managers in most cases, to clarify within the case organisation whether the case was allowed to be disclosed through the dissemination of my research, which includes this thesis. This was immediately accepted in two cases and rejected in one case. For another case, my contact person did not manage to get a decision on this matter prior to the deadline by which I needed to hand in this thesis even though the question was raised three months earlier, after the final case report was approved. Finally, in yet another case, the top management requested that a number of changes were made in the text before they would approve disclosure. I agreed to change the text where I had misunderstood facts but not where the purpose was to present the client organisation in a 'better light'. In general, I concluded that it was more reasonable to make the case anonymous. Ultimately, in order to treat all cases equally, I decided to anonymise all of them, despite the fact that the names of two cases could have been disclosed.

3.4 Unused interviews and field notes from a three-month office stay at Sweco A/S

As mentioned previously, I conducted more interviews than I could manage to include in any of the papers. These not included interviews are listed in Table 11. They were audio-recorded and transcribed but never analysed and included in any paper.

Table 11 Unpublished interview data.

No.	Interviewee	Relevance to the study	Duration
1	Head of estates management	Head of both operational staff and project managers. Experienced with obstacles in cooperation between the two. Furthermore, experienced with FM difficulties in newer buildings in her building portfolio.	53 min.
2	Operational staff, responsible for HVAC, marine engineer	Experienced in building operation, especially within HVAC and BMS. Has been involved in many building projects of various size.	30 min.
3	Head of campus operation and digitisation	Experienced in obstacles in cooperation between operation and projects. Experienced in operation difficulties, especially regarding digital documentation, in new buildings.	1.05 hrs.
4	Head of operation	Experienced in building operation. Experienced in operation difficulties in new buildings. Furthermore, experienced in ship projects.	59.30 hrs.
5	Coordinator of the programme 'From projects to operation'	Experienced in coordinating and developing procedures for ensuring operational considerations in building projects.	1.08 hrs.

For the purposes of this PhD study, I changed my office setting from my office at the Technical University of Denmark, DTU, to the open-plan office of the Sweco consulting company's FM department. First, this situation lasted over a three-month almost full-time period. Subsequently, it occurred every Monday for approximately one year. I did not carry out any work on behalf of Sweco, I simply continued my work on the study and participated in their employee meeting, lunches, etc.

Since my identity as a PhD student and researcher was fully revealed (Saunders *et al.*, 2016), including my research topic, many employees took the opportunity to discuss and share their experiences with me. I took the opportunity to discuss my preliminary findings with them and to ask whether or not they matched their experiences. I made notes (Saunders *et al.*, 2016) during my stay but never analysed them systematically nor included them in any papers.

The five interviews and field notes from Sweco A/S provided the general background knowledge for considerations made in this theses, although they were not published in any paper.

3.5 Validation, reliability and generalization

Validaton, reliability and generalization are important aspects of any research. In the following, I account for these three aspects in regard of this research projects.

3.5.1. Validity

Validity is asking the question: Why should we believe your findings? (Maxwell, 2008). Maxwell (2008) presents a checklist of seven strategies to ensure validity in qualitative studies: Intensive and long-term involvement, rich data, respondent validation, searching for discrepant evidence and negative cases, triangulation, quasi-statistics, comparison. Not all seven are applicable in every study (Maxwell, 2008). In this study, the following was done to ensure validity.

Rich data. Both in regard of the entire study and the individual steps, rich data was collected. Interviews were recorded and transcribed and data for all cases included (except one ship case, which was added late in the study) more than one interview and archival documentation.

Respondent validation (Maxwell, 2008)/Member checking (Schwartz-Shea and Yano, 2012; Creswell, 2014). In the multiple case study, the individual case reports were sent to the interviewees in order to have the gathered information confirmed. In one case, this was followed with a meeting. As the reports had a descriptive nature, this was a possibility. Had the reports been more interpretive, member checking could have been problematic (Schwartz-Shea and Yanow, 2012).

Searching for discrepant evidence and negative cases. I have continuously been looking for discrepant evidence and I have kept an eye for pieces of data that did not fit well into the explanation I was about to build.

Triangulation (Maxwell, 2008; Yin, 2014; Creswell, 2014). Triangulation was applied to the study in several ways. First, the five steps allowed me to combine data collected across steps. An example is the performance gap typology (presented in paper C) based on a combination of expert interviews, focus group interviews and workshops. Both the single case study (described in paper A and B) and the multiple case study included data triangulation. In fact, the possibility of using multiple sources of evidence is one of the strengths of the case study method (Yin, 2014). In all cases, the interviews were supplemented with archival documentation and/or observations. Unfortunately, the access to archival documentation was limited in case three. Additionally, in most cases, I interviewed more than one person.

Quasi-statistic. I tried to apply a quantitative view on the use of tools and methods in the multiple case study by mapping how many tools and methods were used in the individual cases. It soon became clear, that this was not sufficient to give insight into how much effort was put into integrating operational knowledge as one tool took up a few hours in one case whilst much more in another. I gave up on counting tools and methods and instead developed rich description of how the tools and methods were used in the 5 individual cases instead. Paper F gives an example of a rich description of the tools 'Design review by operational staff'.

Comparison. The data collected for this study allowed for comparison between projects of the same type as well as other types.

3.5.2 Reliability

Reliability is about determining whether another researcher doing the same study will come to the same conclusion as me (Yin, 2015). The idea of reproducing the exact same study is not applicable to qualitative research (Schwartz-Shea and Yanow, 2012; Bryman and Bell, 2015) like this study, which includes semi structured interviews and case studies. Alone the fact that my presence contaminate the data (see section 3.6.2) and the role my personal prior knowledge play (see section 3.6.1 and 3.6.4) make replication impossible.

However, in order to increase reliability, I continuously discussed analysis and results with other researchers (Brymann & Bell, 2015; Saunders *et al.*, 2016), both at DTU and at the repeated visits at NTNU in Trondheim.

In addition, I took advantage of my advisory board, whose members were experienced with either building projects and FM or large ships and FM. In each advisory board meeting, I presented my preliminary findings, and asked the participants to share how my findings fitted with their experiences.

Moreover, more informally, I discussed my findings with practitioners in connection with the many presentations I gave during the study, which are listed in Appendix 8, and during my time at the Sweco office.

Finally, for further validation of the multiple case study, findings from the expert interviews and cross-case synthesis were presented to and discussed with (other) practitioners from the ship industry first and with people experienced with either ships or buildings second. This was done in two meetings described as focus group interviews in Paper F and listed in Table 12.

Table 12 Multiple case study's validation focus group interviewees

No.	Interviewee(s)	Relevance to the study	Duration
1	1 captain 1 self-employed consultant	Experienced in ship operation and ship design.	1.44 hrs.
2	2 associate professors at the Copenhagen School of Marine Engineers 1 FM consultant 1 FM professor, DTU (part of advisory board)	Experienced in FM, construction projects and ship operation.	1.30 hrs.

3.5.3 Generalizability

Generalizability deals with the question of whether the results are transferable to other settings (Bryman and Bell, 2015). Yin (2015) describes two types generalizability. One is statistical generalizability, where important factors are sample size and sample variation. In a case study like mine, this type is not much of relevance. I never chose the cases to represent all cases. On the contrary, they were chosen to be examples of best cases. Moreover, the number of cases were not chosen to reach a certain percentage of all cases.

The other is analytical generalization, which is of much more relevance to this and other qualitative studies (Flyvbjerg, 2006; Yin, 2015). This type of generalization addresses whether the case study is suitable for theorizing. As for experiments, theories can be developed based on a single case study (Flyvbjerg, 2006).

To allow readers to judge transferability of my findings for themselves, this thesis as well as the six papers - to the extend word limitations of scientific papers allow it – contain thick descriptions of my research design and findings (Saunders *et al.*, 2016).

3.6 General reflections on methodology

Besides the reflections on limitation of the methods mentioned above, I here describe a few other reflections on the methodology.

3.6.1 Role of prior knowledge and accessibility

As I already was an experienced project manager of construction projects in FM organisations at the time I started this study, I already had knowledge on both building operation and building projects, including design processes and the difficulties with integrating operational knowledge in them. In contrast, my knowledge concerning ship design and ship operation was practically non-existent. This affected my research in different ways. I spent very little time getting familiar with the nature of building projects, whereas I spent a lot more time getting an overview of ship projects. This is for instance reflected in the uneven number of expert interviews. I simply needed additional interviews to collect the pieces necessary to understand the nature of the projects, including how they were organised and which tools and methods, specifically, they used to integrate operational knowledge into the design processes for new ships. Furthermore, my well-established network within building FM and building design provided me with easy access to interviewees and cases, whereas I needed to put more effort into getting access to the ship building industry. It also meant that I had less ‘to choose from’ with respect to ships. This concerned both the data collection and findings validation.

Having prior knowledge comes with both benefits and challenges. The same is true for the opposite, ‘stranger-ness’ (Schwartz-Shea and Yanow, 2012), which was the situation for me in relation to the ship cases. Being a stranger in the shipbuilding industry gave me the opportunity to take the unspoken less into account and to avoid taking-for-granted the tacit knowledge of my interviewees. I believe my ‘stranger-ness’ in the ship cases helped me minimize confirmation-bias (Schwartz-Shea and Yanow, 2012) and also helped me have a ‘fresh’ view of building projects. As for many researchers conducting case study research, I experienced that my preconceived view on e.g. the role the affiliation of the project manager plays on tools and methods, was falsified (Flyvbjerg, 2006).

3.6.2 Researcher contamination

Throughout this study, I experienced that I, as a researcher, influence the data I collect through, for instance, the questions I pose and the answers that I ask my interviewees to elaborate on. Schwartz-Shea and Yanow (2012) call this ‘researcher contamination’. This may be the reason why the observations I made in one of the building cases turned out to be very interesting. I wrote a conference abstract and gave a conference presentation solely based on my observations and thoughts from those two meetings (see List of other publications in appendices). My stay at Sweco’s office also gave me valuable insights, although this was in a more indirect and less rigorously documented way. Further observations or ‘shadowing’ (Bryman and Bell, 2015) of key personnel would surely have been fruitful as my contamination would have been minimized, although never eliminated.

Especially in the light of my finding that the integration of knowledge is more dependent on individuals than on tools and methods, observations would have been an interesting method. Moreover, shadowing would perhaps have revealed other and more informal ways of transferring knowledge, which my respondents did not mention if they don’t consider e.g. social interaction as a knowledge transfer process.

3.6.3 Balancing ships and buildings

Balancing buildings and ships has been challenging not only in terms of collecting and analysing data but with respect to publishing papers, too. In the first version of Paper C (A facilities manager's typology of performance gaps), the typology was based on the empirical data from both the ship and the building industries. However, the journal reviewers questioned whether the ship part was more disturbing than assisting the point we were trying to make. Consequently, we rewrote the paper, this time without the ship part. Surprisingly, although it weakened the empirical basis for the study (reducing ten interviews to four), it did not change the typology nor the finding that the types were interrelated. This shows that these challenges of balancing interrelated potential performance gaps are a shared problem. It also shows that the comparison helped shed light on an issue and to see the gaps more clearly - as the comparison was done, the content could stand alone.

3.6.4 My own matter of concerns influence on findings

A final remark to reflections of methodology is that I soon experienced that research is about making choices. This includes selecting which initial findings from the data to further analyse, validate and not least disseminate in papers. My qualitative methods resulted in a rich data set, in which I could see the outline of several interesting findings. My choice of findings to further investigate was guided by several things illustrated in Figure 10. This included research questions, prior knowledge e.g. from the literature, assumptions, previous experience and so forth. Another researcher could have emphasised other findings. Thus, you could say, that the matter of concern of key actors plays a role in research, too.

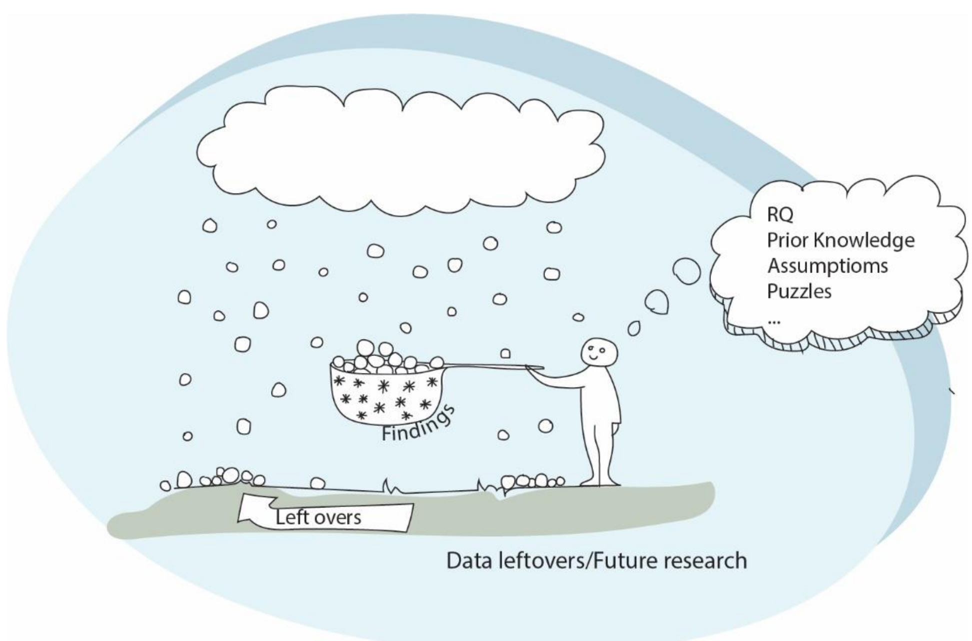

Figure 10 Choices in research are based on many things.

4. Findings

This thesis is based on six peer-reviewed papers - five of which are published while one is accepted for publication and is awaiting date of publication. This section provides a summary of each paper, while full-length papers can be found in the appendices. My contributions to each paper are described in the List of papers (page x).

Summaries of all papers are presented in this chapter in chronological order of their data collection. Consequently, Paper A is presented as the first paper despite the fact that it was published recently (in 2019). Paper E is an exception, as data for this paper was collected before paper D. Table 1 provides an overview of the six papers, including their research aim, connection to the thesis research questions and whether they concern buildings or both buildings and ships.

The first two papers (A and B), concern the need for deliberate actions that would enable the integration of operational knowledge into design processes and focus on the tools and methods that could be used to achieve it. This is in accordance with the strong emphasis on tools and methods found in the literature on the topic. Moreover, paper A and B investigate conditions of importance to the integration of operational knowledge into design, such as the organisation of the building client. Papers A and B focus only on building projects and form a solid base of knowledge on the topic in regard of buildings, which is compared with large ships in paper E and F.

The following two papers, C and D, also concern buildings alone. They study the 'outcome' of the projects because I became aware that little research has been carried out to bring together different aspects of building performance that are relevant to FM. Studying the 'outcome' offer new insight into the 'input' of operational knowledge in the design processes.

Finally, Paper E and F compare projects of building and ship projects in regard of integrating operational knowledge in to the design process. Paper E follows up on paper A and B by focusing on tools and methods and on general conditions of the project. Paper F focuses on the client's project manager and gives more attention to how the knowledge is 'picked-up' by the project team and less on how knowledge is captured and stored.

In the following sub-sections, I present a summary of each of the six papers.

4.1 Paper A: Initiatives to integrate operational knowledge in design: A building client perspective

Rasmussen, H. L., Jensen P. A., Nielsen S. B. and Kristiansen A. H. (2019) 'Initiatives to integrate operational knowledge in design: A building client perspective', *Facilities*, 37(11/12), pp. 799–812.

The purpose of this paper is to identify initiatives to integrate operational knowledge into building design, with the aim of realising sustainability potential, and to bridge the performance gaps found in newly built facilities. In line with findings from the literature, the study focuses on the building client as the main actor responsible for implementing such initiatives. From the literature, 31 initiatives are identified from primarily three sources, including research and the Danish guideline for practitioners: 'Operation-based construction process' (Due *et al*., 2016). These 31 initiatives serve as the basis for a single case study and a questionnaire survey. The case organisation is the FM organisation of the Technical University of Denmark (DTU); Campus Service. It was chosen because it both builds and operates the university facilities and it, thus, has the opportunity to integrate knowledge from operation into its new building projects.

The findings from the case study indicate that many of the 31 initiatives are either already implemented or their implementation is planned in the near future. The survey includes a questionnaire with responses from actors involved in five new swimming facilities, showing that less initiatives are implemented in those projects than in the case organisation.

Moreover, the DTU Campus Service case study further adds 11 initiatives that are not described in the reviewed literature. Thus, the paper presents a gross list of existing initiatives, 31 derived from the literature, 11 derived from the case study. The 42 initiatives greatly differ in both size and character.

Furthermore, the study shows that, in particular, three building client organisation parties should be involved in initiatives: Top management, building client division and operation division, as illustrated in Figure 11.

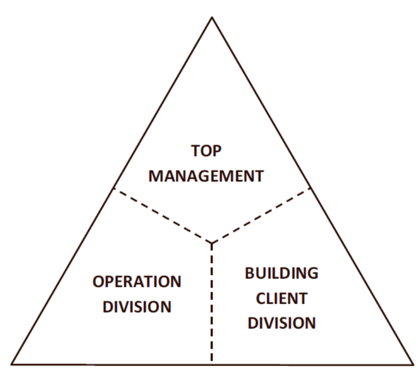

Figure 11 The three-partite building client, Paper A.

The paper recommends that building client organisations place responsibility for the initiatives - and thus the integration of operational knowledge in projects - not only on the building client division but also on top management and the operation division. The paper presents a revised list of the 42 initiatives, organised in accordance with which party is found to be best suited to implement the initiative, although emphasis is placed on the fact that cooperation between the three parties is a necessity for integrating operational knowledge into new building projects. Table 13 shows the revised list organised by responsibility. Numbers refer to the gross list, which can be found in paper A.

Table 13 Initiatives organised by responsibility, Paper A.

	Top Management should consider:
32	Clear statement that operational friendly and energy efficient buildings are a high priority
34	Establish a professional building client/construction management division
35	Operation Division represented in management group
36	FM considered a strategic discipline
37	Care for good relations between Building Client Division and Operation Division
	Building Client Division should consider:
1	Continuous Briefing
2	Detailed Building Brief
3A	Project review externally
4	Public Private Partnership (PPP)
5	Contractor responsibility for operation and maintenance
7	Technical Due Diligence
10	Use of Life Cycle Cost assessments
A	List of demands to include in the building brief (initiatives 11, 12, 13, 14, 15, 16, 17, 18, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31 from gross list)
39	Log deviations from the guidelines and standards for building projects (see initiative 9)
41	Establish a safety net to secure considerations of comments and demands mentioned in wrong phases
42	Care for good relations between design team, construction team and Operations Division.
19	Demand of evaluation of consequences of significant changes during the design phase on operational friendliness, energy efficiency etc.
20	Demand of evaluation of consequences of significant changes during the construction phase on operational friendliness, energy efficiency etc.
	Operation Division should care for:
9	Prepare guidelines and standards for building projects
B	Specifications of demands to include in the building brief
17	Specifications on demands of operation- and maintenance material from contractors (and preparations to receive documentation according to hand-over time schedule)
15	Specifications of demands of operational plan and operation budget
40	Agreements on how and what is included in internally reviews conducted by the operational staff
3B	Project review internally
6	Continuously commissioning
8	Plan for when and how the right competences should be involved in the project to include operational knowledge in the project.
21	Specific demands to the operational organizations role in starting up the operation

Additionally, the paper emphasises that it takes deliberate action to fully implement initiatives and achieve a positive effect of the initiatives on the performance of new buildings. The paper presents a model of four levels, with increasing positive effect on operational friendliness of the completed building projects (Figure 12).

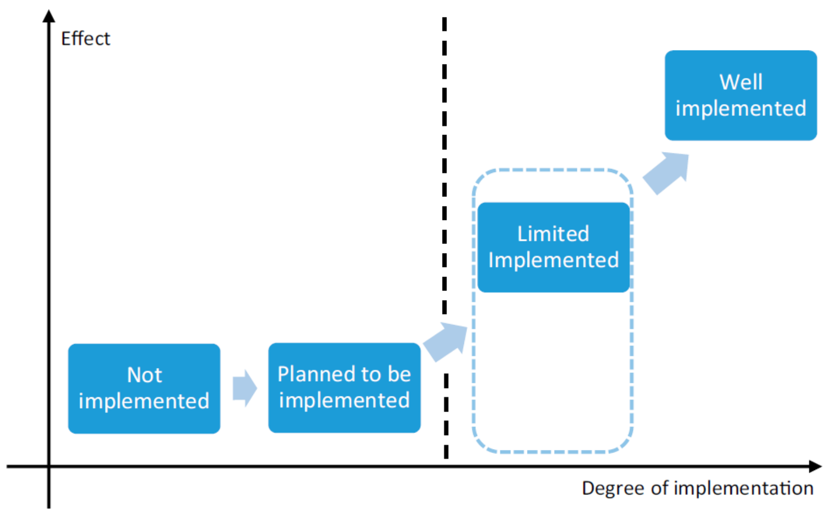

Figure 12 Level of initiative implementation in relation to effect, Paper A.

The paper concludes that many initiatives have already been developed and implemented in practice. However, it is not sufficient to simply review whether an initiative is implemented or not, one also need to evaluate how well they are implemented.

4.2 Paper B: Knowledge transfer between building operation and building projects

Jensen, P. A., Rasmussen, H. L. and Chatzilazarou, S. (2019) 'Knowledge transfer between building operation and building projects', *Journal of Facilities Management*, 17(2), pp. 208–219.

The purpose of this paper is to examine knowledge transfer between departments of building operation and building project management through a single case study. The same case organisation as the one used in Paper A, DTU Campus Service, was chosen. Whereas Paper A focuses on the transfer of knowledge from operation to projects, this paper also investigates the transfer of knowledge from projects to operation.

Drawing on theory from the sphere of knowledge management - explicitly, knowledge transfer - the study identifies a number of tools and processes that the case organisation has implemented to facilitate the transfer of knowledge between the operation and maintenance department (O&M) and the project management department (PMO). The study finds that the case organisation deliberately works on reusing the knowledge they possess from many years of operation in new construction projects. However, the study also shows that more focus has been given to *interaction* (Kahn, 1996) activities, supporting a codification knowledge transfer strategy. Less focus has been given to *collaboration* (Kahn, 1996) activities, supporting a personalisation knowledge transfer strategy. Both push and pull knowledge transfer mechanisms (Jensen, 2012) are used by the case organisation but less knowledge is pulled from the PMO by the O&M.

The paper provides examples of tools and methods for enabling knowledge transfer between the two departments in the investigated case organisation. They include knowledge repositories in the form of a shared digital project document archive (project web) and design standards. Both contain codified knowledge that can be stored as well as pushed/pulled on demand. An example of a tool that does not solely depend on codification is a review meeting, where operational staff orally review design proposals representations - e.g. text, drawings or 3D models. Table 14 gives examples of the knowledge transfer tools in DTU Campus Service and indicates whether the tool aims to push or pull knowledge and whether the direction of knowledge transfer is from O&M to PMO or vice versa. Finally, the paper suggests that a knowledge broker is a possible way of improving the knowledge transfer between the two parties.

Table 14 Examples of tools used to transfer knowledge, Paper B.

Mechanism	Direction	Examples
Push	O&M→PMO	Design standards (generic)
	PMO→O&M	Phasegate meetings: information about the project is given to O&M
Pull	O&M←PMO	Documents and drawings put in ICT-based tool
	PMO←O&M	Phasegate meetings: feedback from O&M

4.3 Paper C: A facilities manager's typology of performance gaps in new buildings

Rasmussen H. L. and Jensen P. A. (2020) 'A facilities manager's typology of performance gaps in new buildings', *Journal of Facilities Management, 18(1),* pp. 71-87. DOI 10.1108/JFM-06-2019-0024

Paper C addresses the issue that the literature seems to define performance gaps as an *energy* performance gap, which is a contradiction to the empirical data collected in this PhD project. The aim of the paper is, therefore, to nuance the definition of performance gaps to understand what types of performance facilities managers are concerned about in new buildings. This is important to know as it influence the way facilities managers are involved in projects of new buildings.

An initial typology of 8 performance gaps was developed from expert interviews with representatives coming from the building industry. The initial typology was presented to and discussed in two focus groups before it was further developed. The typology, now consisting of 12 performance gap types, was ultimately validated in three workshops.

The typology, see figure 13, illustrates that facilities managers are concerned about several performance gaps other than the energy performance gap. Examples are 'unsatisfactory indoor climate', 'lack of adaptability/flexibility' and 'not meeting regulatory requirements'.

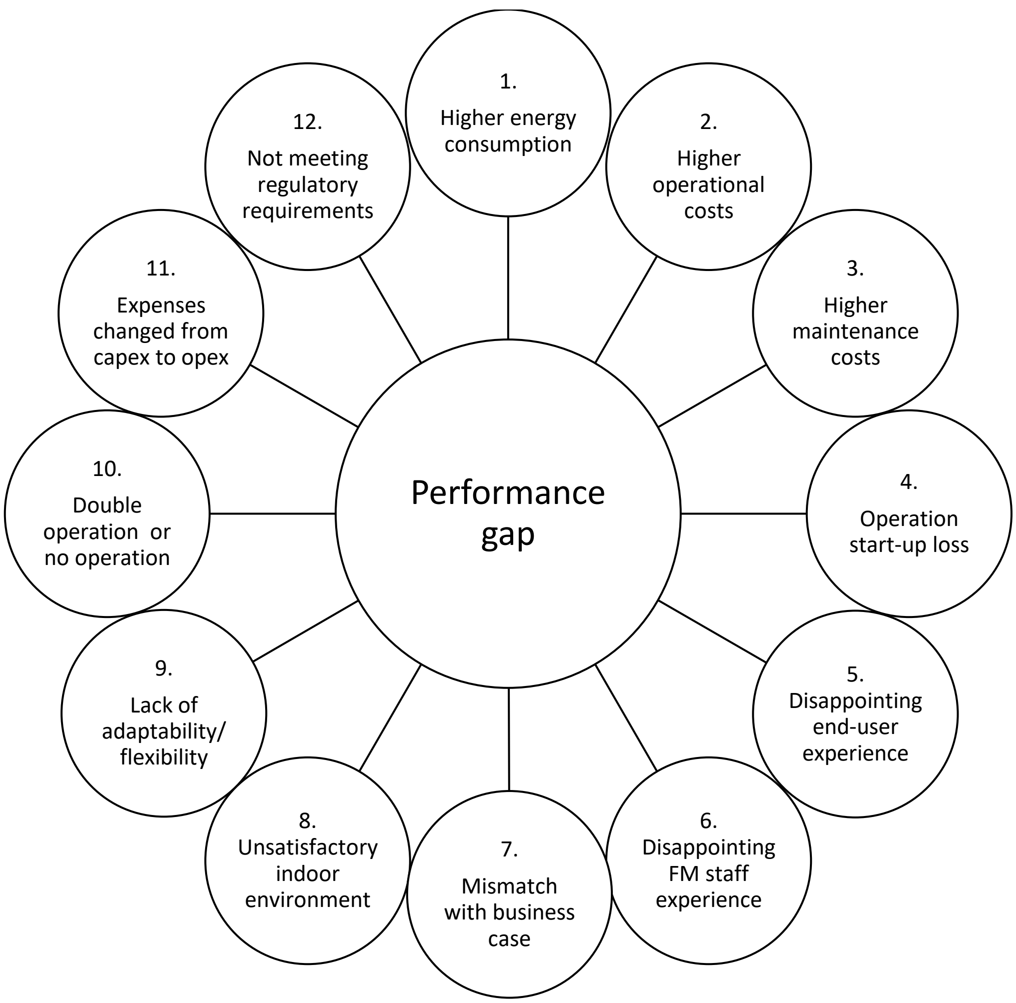

Figure 13 Typology of performance gaps in newly built buildings from an FM perspective, Paper C.

The hierarchal order of the gaps is project specific and depends on the purpose of the specific new building. For example, ‘higher energy consumption’ can be fatal in one type of buildings but not necessarily in other types. Similarly, ‘disappointing user experience’ can be fatal in some buildings but not in others. Consequently, the typology is illustrated as a flower (see Figure 13) rather than as a list.

Moreover, the 12 types are interrelated. Efforts to bridge one gap can cause that other gaps are either opened or bridged. This can happen in at least three ways. First, actions to bridge one gap can cause that another gap opens. Second, actions to bridge one gap can result in bridging other gaps, too. Third, the opposite of the second, one gap resulting in another gap, as a snowball.

Despite the fact that FM is a broad field, most FM staff members are specialised in one or few FM tasks - for example, operation and maintenance, cleaning or energy management. This possess a risk when involving FM staff in building projects, as one can assume, that they are likely to primarily take their individual tasks into account. This potentially causes sub-optimization, thus make involvement of FM staff in design processes counterproductive.

Findings that the hierarchy of the gaps are project specific and that gaps are interrelated, together with the fact that most FM staff are specialised in one or few tasks, call for someone in building projects to balance the different interests of the involved individuals.

Finally, the paper remarks, that the present overwhelming attention in the society, not least from policy makers and researchers, on bringing down energy consumption of buildings need to include attention towards other – interrelated - types of performances as well.

4.4 Paper D: The legacy from construction to FM: The good, the bad and the ugly

Rasmussen, H. L. and Due, P. H. (2019) 'The legacy from construction projects to facilities management in Denmark: The good, the bad and the ugly', in *Proceedings of EFMC* in Dublin, Ireland, June 2019, pp. 168-177.

The purpose of this paper is to further investigate the performance gaps developed in Paper C by identifying the specific difficulties that FM can experience in new buildings. Thus, continuing the path of exploring difficulties that facilities managers are concerned about in new buildings. Additionally, the paper investigates what difficulties are most often experienced, according to the facilities managers of new buildings in Denmark.

To fulfil this purpose, we first identified specific difficulties from the literature and from presenting and discussing a preliminary list of 22 difficulties with practitioners. This resulted in 35 specific difficulties divided into six categories: 1: Indoor climate, 2: O&M of technical systems, 3: O&M of building parts, 4: Sustainability, 5: Functionality, and 6: Others.

Next, we conducting a web-based questionnaire survey in which we asked the respondents to indicate, using a 5-point Likert scale, to what degree they experienced each difficulty - from 'never experienced' to 'experienced to a high degree'. The respondents were FM practitioners in buildings that were less than five years old and a total of 76 completed questionnaires are included in the results. We conducted a simple analysis by calculating the mean value of the 35 difficulties and ranking them accordingly. In table 15 the 35 difficulties are ranked by mean value.

Table 15 The 35 difficulties ranked by mean value, Paper D

Rank	Category/No.	Difficulty	N=	Mean value
1	6.3	Inadequate or poorly structured O&M material e.g. missing information in the O&M software/ lack of upload of information to the software	51(47)	3,36
2	4.6	Unexpected high energy consumption due to the lack of commissioning of the technical installations	52(51)	3,24
3	6.4	Inadequate or not updated blueprints to the FM-staff	51(49)	3,18
4	3.2	Unexpected costly og difficult cleaning of windows externally og internally due to lack of accessibility	52(48)	3,06
5	6.1	Unexpected operating investments due to the change of costs from Capex to Opex	51(49)	3,04
6	1.1	Poor indoor climate – too hot	58(56)	3,04
7	1.4	Lacking or difficult coordinated control of heating and cooling	59(57)	3,00
8	3.7	Damage to doors and windows forced open by the users using e.g. wedges	52(50)	2,98
9	1.2	Poor indoor climate – too cold	59(57)	2,86
10	2.2	Unexpected costly O&M of technical installations due to limited access or costly spare parts	54(52)	2,83
11	4.1	Higher energy consumption than expected	52(40)	2,83

12	3.1	Unexpected costly cleaning of surfaces due to choice of materials, e.g. on floors and walls	52(46)	2,80
13	2.4	Inappropriate or expensive options for changing light sources and servicing light fixtures	54(49)	2,78
14	3.6	Difficult or expensive change of building components – e.g. windows and façade panels	52(48)	2,75
15	2.3	Floors in wet rooms with incorrect or defective slope and / or drainage	54(52)	2,62
16	2.1	Limited possibility to use auxiliary tools such as lifts due to interior design or construction	54(48)	2,60
17	1.3	Poor indoor climate – draught	58(57)	2,60
18	1.5	Poor acoustic indoor climate - noise from people, machines, surroundings	59(57)	2,60
19	3.3	Unexpectedly rapid wear and tear of floors due to inappropriate material selection	52(48)	2,58
20	5.1	Inappropriate location and / or layout of kitchen, cleaning room, waste room	52(49)	2,43
21	5.2	Inappropriate location and or layout of rooms with technical installations	52(49)	2,41
22	5.5	Restricted adaptability of office spaces to changes e.g. during to organizational changes	52(45)	2,40
23	4.2	Too few energy og water meters	52(44)	2,40
24	5.4	Lack of opportunity to use rooms for multiple purposes during the day	52(47)	2,36
25	6.2	Lack of compliance on regulatory requirements, fire prevention demands, safety requirements etc.	51(50)	2,32
26	4.4	Difficult waste handling	52(45)	2,31
27	2.5	Poor physical working conditions for the FM-staff. E.g. reduced ceiling height og poor daylight conditions	54(53)	2,30
28	3.4	Unexpected or fast discoloration/ patina of internal building components	52(49)	2,27
29	4.3	The lack of bicycle parking, poor accessibility of the bicycle parking and/or lacking shower facilities for the bikers	52(45)	2,24
30	3.5	Unexpected or fast discoloration/ patina of external building components	51(47)	2,23
31	6.5	Unexpected need for double operation due to delay in the construction project	51(46)	2,22
32	4.5	Lack of automatic control of the light	52(51)	2,06
33	5.3	Inappropriate location or interior design of the core facilities of the enterprise e.g. class rooms, offices, meeting rooms and production facilities	52(49)	2,00
34	6.7	The architecture does not fulfil the function or mirrors the culture of the enterprise	50(47)	1,89
35	6.6	The architecture is not aligned with the brand of the enterprise	50(43)	1,72

Besides the indication of the 35 difficulties listed by us, respondents were given the option to add other difficulties experienced in their new buildings, within each of the six categories. Eight respondents added difficulties to category 1: 'indoor climate', whereas only 2-4 other difficulties were added to the categories 2-6. The added difficulties included noise, smell, lack of individual control and lack of fresh air.

The study showed, as illustrated in Figure 14, that facilities managers find it challenging to obtain the digital material of a proper quality from the building project (O&M materials and drawings). Increased energy consumption, due to a lack of technical installation commissioning, and poor indoor climate (too hot, too cold and difficult to control) are other common challenges, according to the respondents. Difficult or expensive window cleaning is also found among the most often experienced difficulties. So are unexpected operation investments resulting from the change in costs from capex to opex in the building projects. Finally, damage to doors and windows resulting from users forcing them open was a problem often experienced by the respondents and measured by the mean value of the indications on the Likert scale.

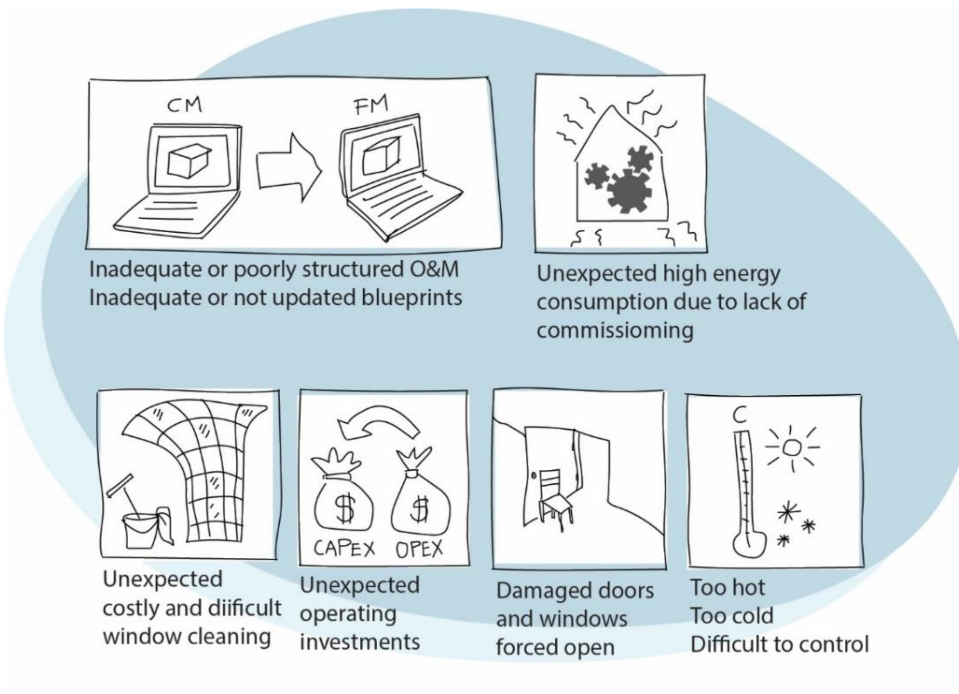

Figure 14 The most experienced difficulties, according to survey respondents.

4.5 Paper E: Tools and methods to establish a feed-forward loop from operation to design of large ships and buildings

Rasmussen, H. L. and Jensen P. A. (2018) 'Tools and methods to establish a feed-forward loop from operation to design of large ships and buildings', in *Proceedings of EFMC* in Sofia, Bulgaria, June 2018.

Whereas the Papers A, B, C and D concern buildings, this paper compares ways to establish a feed-forward loop from the operation to the design of buildings and large ships. The investigation aims at identifying the differences and similarities related to enabling a feed-forward loop from operation to design. Furthermore, the paper aims to identify the relevant tools in one of the two project types that could potentially be adopted by the other.

The study is based on a literature review and expert interviews. It shows that the establishment of a feed-forward loop from operation to design not only depends on tools and methods but also on what is called 'general conditions' in the paper. General conditions are contextual conditions that vary from project to project and from ships to buildings. Both similar and different general conditions for ships and buildings are identified. The three-partite building client identified in Paper A is found to be a similarity, whereas one identified difference is that ships are often built in series, while buildings rarely are. Similarities and differences in general conditions are listed in table 16.

Table 16 General conditions, Paper E

A1: General conditions, similarities: • The three partite client. • Shared goal and team spirit (between building client and operation) is important. • Challenged by different focal point when design team and operational staff work together. • Limited learning from operation to design within series. • Limited use of IT based tools to store and transfer operational knowledge to design. • The cost of operation stage is by far larger than construction cost.
A2: General conditions, differences: • Overlapping competences in ship design • Naval architects are engineers with a background from technical universities or similar • Building architects are "artists" with an aesthetic focus from academies of fine arts or similar. • Public building clients for large ships are rare • Ships are mobile and built at locations independent on where they are going to be used • New ships are decided with strong business case focus • Ships are in general more alike (more possibility to learn across series) • Different professions do the first design sketches in a new project.

With respect to tools and methods, both similar and different ones are found in new building and ship projects. LCC and design review by operational staff are tools that are found in both industries. Table 17 shows tools and methods found used in both type of project, mostly in ships and mostly in building projects.

Table 17 Tools and methods, Paper E

B1: Tools and methods, similarities: • Reviews of the design on different stages by operational staff. • Workshops with different stakeholders, including operational staff, on different stages • Key numbers (measurements) for parts and interior. • Commissioning • Case studies or study trips for stakeholders for inspiration on different aspects of the design. • Total Cost of Ownership/Life Cycle Cost is important, but with short pay-back time
B2: Tools and methods, ships only (mostly) • On-boarding operational staff to the design team. • On-boarding design staff to operation (the design managers board a ship for a week or two) • Captains report. • Survey among operators of ”problematic suppliers” • Extensive model testing during design • Classification (Certification schemes)
B3: Tools and methods, buildings only (mostly) • Environmental Life Cycle Assessment (LCA) • Iterative design process. • 5 year guarantee period

Among the tools and methods found in the design of ships but not in the design of buildings are two especially interesting tools which we call ‘on-boarding’. First, the on-boarding of operational staff to a design team is where sea crew staff members are physically placed with the design team to provide continued and ad-hoc input, reviewing and supplementing the work of the design team. Second, the opposite, on-boarding of design team staff to the operation team. The latter type was described as a two-week stay for key design staff members on board one of the ship owner’s ships in order to experience the ship’s operation and talk to the operational staff while on board.

Moreover, drawing from the research field of knowledge management, the study investigates two approaches to knowledge transfer: the technocratic and behavioural approaches (Earl, 2001). The on-boarding tools are identified as examples of tools based on the behavioural approach to knowledge transfer.

4.6 Paper F: The challenge of integrating operational knowledge into building and ship design

Rasmussen, H. L. (forthcoming) 'The challenge of integrating operational knowledge in building and ship design', accepted for publication in *Facilities*.

The objective of Paper F is to investigate and compare how operational knowledge is integrated into the design process of buildings and large ships. The study has a special focus on the role of the project manager's affiliation and competence because the literature appoints the building client with a key role in terms of integrating operational knowledge into design.

The empirical data was collected in three steps: 1) ten expert interviews; 2) a multiple case study of five specific projects (three ferries and two buildings); and 3) two validation focus group interviews. Data collection for the cases consisted of in-depth interviews (eleven individual and three focus group ones). In total, 26 interviews were conducted. Table 6 (chapter 3) shows the basic information about the cases.

Each of the five cases were first described in relation to the themes listed in Table 10 (chapter 3) in individual reports. Subsequently, the themes were compared and analysed across the cases (Yin, 2014). Finally, the findings were discussed in two focus group interviews for validation purposes.

Analysis included the identification of the specific tools and methods to integrate operational knowledge implemented in the design process of the individual cases. The individual reports described *which* tools and methods were implemented and *how* they were used in the cases. Moreover, the individual reports included identification of 'general conditions', as previous findings indicate that this plays a role in the integration of operational knowledge (based on findings from Paper E). Examples of general conditions included in the individual reports are the organisation of the client company, organisation of the project, education and experience of key actors, and criteria of success. Finally, the five individual reports were compared across cases to identify similarities and differences. Table 18 provides an overview of the cases, the affiliation of the projects manager and the use of tools and methods.

Table 18 Examples of findings in the multiple case study, Paper F

Industry	***Ships***			***Buildings***	
Case	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**
Stage when studied	Construction	Design	Operation	Operation	Design
Affiliation of project manager(s)	Top Management	Top Management	Operations Division	Building Client Division	Building Client Division
Implemented tools	Few	Many tools, light	Few	Many tools, heavy	Many tools, heavy
Opex in business case	Yes	Yes	Yes	Yes	Yes
Opex in design	Yes	Yes	Yes	No	No

For both ships and buildings, the need to integrate the operational knowledge possessed by internal operational staff increases if the facility under design is going to be part of a larger facility portfolio. This comprises specific demands to ensure that the new facility fit into the portfolio or larger project. Examples include technical systems that are able to correspond across facilities, such as logistic systems (as in case 5), building management systems (as in case 4) or fire safety equipment (as in case 4). In the third case (ship), the project manager described a need to make the interior design recognisable to customers; thus, a new ship needs to fit the visual expression of other ferries when part of a portfolio. Two of the ship cases did not explicitly need to fit into a portfolio: Case 1 was the first ferry that the client purchased and the new ferry in case 2 was replacing two old ferries. However, since they still need to fit into the harbours, they cannot therefore entirely be considered to be 'stand-alone' facilities. In the building cases described in Papers A, B and F, the requirements to ensure a new facility's fitness to the portfolio are given in detailed codified generic documents (design guidelines) which serve as appendices to a building brief or tender. However, this does not guarantee that the requirements would be incorporated into the actual design, as found in Paper B. The clients of the ship cases did not have generic detailed design guides. Instead, some ship clients built the requirements for new ships based on the requirements of previous ships, adding 'lesson learned' aspects and adjusting them to their new project. In one ship case, the ship owner's requirements for the new ship were described in bullet points in an e-mail. Four bullets described the requirements for the new ferry (speed, energy type, capacity and the possibility to extend the battery pack) and four bullets described the requirements for the shipyard's bid.

An example of a tool implemented in all five cases is design review by operational staff. However, the study shows that the case organisations implemented and were using this tool very differently. In some cases, the tool had evolved into a project in itself, whilst in other cases it was simply embodied in the form of one e-mail sent forth and back. Additionally, the same tool is found to be implemented based on the technocratic approach in some cases, while also being implemented based on the behavioural approach in other cases (Earl, 2001). This shows, that it is not so much a question of whether the tool is used in a project or not but rather how it is being used. Table 19 shows how review by operational staff is done very differently in the individual cases.

Table 19 Design review by operational staff, Paper F

Case	**Stage when studied**	**Action**	**Operation reviewers**	**Type of interaction (primary)**	**Type of review (primary)**
1	Construction	Part of meetings with management company	External	Face to face	'Instant' review
2	Design	Drop-by meeting—once Technical director in steering committee	Internal	Face to face	'Instant' review

3	Operation	Parts of design sent to specific members of staff once Technical director is project manager	Internal	E-mail	Desk work, individually
4	Operation	'Review project' Stage gate reviews: Complete project material and review templates sent to reviewers Additional review on parts of design (by e-mail)	Internal	Spreadsheets	Desk work, individually
5	Design	'Review project' (external facilitator) Facilitating review meetings on specific parts of the design Continuous review by on-boarded operational staff to design team Final review of complete project material	Internal	Face to face	'Instant' review

In the two building cases described in Paper F, the involvement of operational staff became a project in itself, taking up many resources of both the operational and design teams' staff. In one of these cases, the involvement is heavily based on a technocratic approach (Earl, 2001; Vianello, 2011) that employs a strong codification strategy (Hansen *et al*., 1999; Lê and Brønn, 2007). Representatives of the operational division developed detailed generic requirements for new projects, which they front-loaded into every new project. Subsequently, the same representatives reviewed the increasingly detailed design several times in order to control whether the front-loaded knowledge was 'picked up' by the design team and, thus, integrated into the design, as well as to review the design in general.

Nevertheless, findings suggest that the project manager and the design team - in both building cases in the multiple case study - to some extent became dependent on the operational staff to complete tasks that are usually considered to be part of the design team's tasks. For example, the review by the operational staff in one case perhaps had the character of a quality check and thus did not solely focus on operational considerations. In the other building case, involvement of operational staff also became a project in itself. However, it is to a higher degree based on the behavioural approach; for example, an operational staff member on-boarded to the design team.

The study shows that, in the *building* cases, the project managers are affiliated with the project management division, as shown in figure 15. They have experience and are educated in design and construction processes and their job is to complete projects within the agreed time, quality and economy (Winch, 2010). Thus, they have a short-term focus in the projects. They allocate many resources in the project to ensure that operational knowledge is integrated in the design.

In the *ship* cases, project managers are affiliated with either the top management or the operation division (figure 15) and, thus, have long-term interests in the project. However, they allocate few resources to ensure that operational knowledge is integrated into the design process. There is no indication that operation is taken less into consideration in these projects. On the contrary, detailed project-specific operation budgets are only developed in the ship cases, as shown in Table 18.

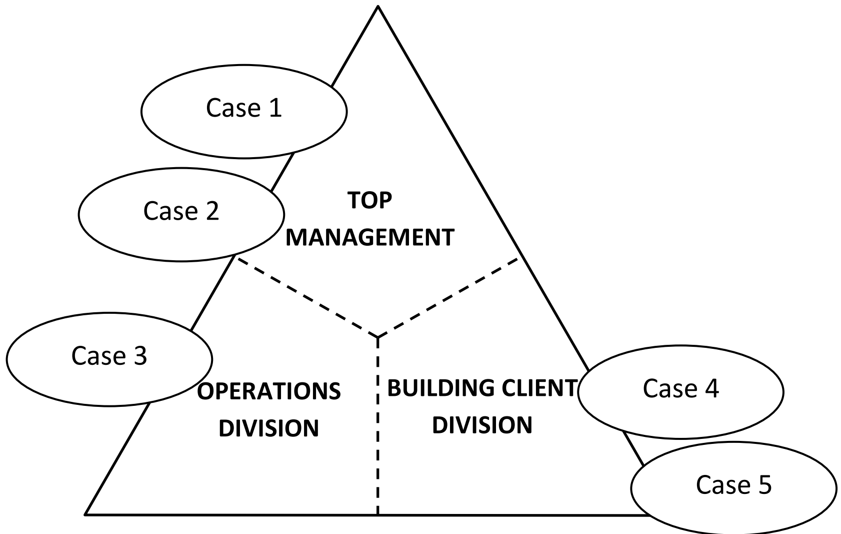

Figure 15 Affiliation of project management in the five cases, Paper F

The study shows that the matter of concern (Latour, 2004; Kreiner, 2010) for the project manager plays a role in terms of how effortlessly operation is integrated into the design process. Against my expectations, less resources are put into the knowledge integration process if operation is the matter of concern for the project manager, which is the case in the three investigated ship cases. However, there is nothing in the findings that suggests that operation is taken less into account in the design processes when less resources are placed into the knowledge integration process. On the contrary, only the project managers of the three ship cases developed and maintained design-specific operation budgets and conducted simple total cost of ownership analysis to compare alternative design proposals, such as safety equipment.

The paper concludes that affiliation, competences and matter of concern of the project manager play an important role in how many resources go into enabling operational knowledge to be integrated into the design process. If operation is the matter of concern of the project manager and operational knowledge to some degree is already internalised, less tools and methods are needed to ensure that operation is considered in the design process. Correspondingly, extensive use of tools and methods appears to be needed if operation is not the matter of concern for the project manager, and little operational knowledge is internalised. In the cases, where operation was the matter of concern, other design matters, e.g. user experience and aesthetics, were limited considered.

The paper recommends future research to focus less on development and implementation of tools and methods and more on how to get operation into the matter of concern for project managers, without jeopardising other important performance parameters.

5. Discussion: Tying together findings

The overall aim of this thesis is to investigate how operational knowledge is integrated into the design process of new buildings with the aim of improving facility performance. To shed new light on the research topic, I have applied two main approaches to the study. One is the comparison between projects for buildings and large ships. The other is the use of theories from the field of knowledge management, particularly knowledge transfer, which is applied as a lens.

The use of the lens of knowledge transfer is more prominent in some of the papers, while remaining more in the background in others. Nevertheless, I have continuously studied the problem through this lens. The lens is not formulated as part of the research question; however, at the end of this chapter, I will elaborate on and evaluate the advantages and disadvantages of this lens, both from a theoretical perspective and from the perspective of practitioners.

As listed in Table 1 and summarised in Chapter 4, the six papers included in the thesis have investigated this issue from different angles, yielding a number of findings. These findings add different pieces to the puzzle of the overall purpose. In this section, I tie together the pieces in order to answer the three research questions (RQs). RQ 1 is addressed mainly in Papers A and B, and partly in Paper F. RQ 2 is addressed in Papers C and D. RQ 3 is addressed in Papers E and F.

5.1 Answering Research Question 1 (RQ 1)

The first research question aims to gain insight into the tools and methods developed to enable the transfer of knowledge from building operation to design, including how and by whom in the building client organisation these tools and methods are used. The research question, which includes these two aspects, is formulated as follows:

RQ 1: Which tools and methods enable the transfer of knowledge from operations to the design process of building projects? Further, what are the important roles and actors of the building client organisation in this knowledge transfer process?

This study identified a large number of tools and methods to enable the transfer of knowledge from operation to design in building projects. Many tools are 'ready to use' and described in both the scientific literature (Jensen, 2009; Jensen, 2012) and in a Danish set of guidelines for practitioners (Due *et al.*, 2016). Others have been developed by practitioners and are described in the literature in a limited way. Many tools and methods are based on the involvement of operational staff in the design process, e.g. by reviewing design proposals or participating in commissioning activities. The findings of the study include a master list of 42 initiatives that a building client organisation can undertake to enable the integration of operational knowledge into design. Thus, a lack of tools and methods does not seem to be the main cause for difficulties in integrating operational knowledge from operation into design in building projects.

The literature on knowledge transfer follows two approaches: a technocratic approach and a behavioural approach (Earl, 2001; Vianello, 2011). The technocratic approach focuses on transforming tacit knowledge (Polanyi, 1966) into explicit knowledge by codification with the purpose of storing and then transferring knowledge from a receiver to a sender (Davenport *et al*., 1998; Reihlen and Ringberg, 2006; Zuo *et al.*, 2013). The behavioural approach defines knowledge as embedded by personalisation in the knowing person; thus, it is impossible to transfer without (e.g.) social interaction (Hansen *et al*. 2010; Pan and Scarbrough, 1999; Hislop *et al*., 2018). This study shows that it is, to a lesser degree, the tool or method itself that represents one of the two approaches, as it is the way the organisation adopts the tool or method. One example is the implementation of design review by operational staff in some organisations in a way best described as technocratic. Here, the review is based on project documentation – drawings and descriptions – and comments are communicated in spreadsheets. In other organisations, the review is based on a behavioural approach wherein design proposals are discussed in meetings with operational staff or by operational staff being moved to the design team.

In the literature, the building client is assigned the role of a key actor in ensuring the integration of operational knowledge into design (Hansen *et al.*, 2010; Fatayer *et al.*, 2019). This study defines three parties within the building client that are of importance to the transfer of knowledge from operation to design, namely the top management, the operations division and the building client division. These three parties are often separated – both organisationally and physically. All three parties are responsible for the successful integration of operational knowledge into design. The findings of this study include a list of initiatives to enable the integration of knowledge from operations into design that are organised by whichever member of the three-partite building client is best suited to be responsible (Table 13). Examples are the 'client's design guidelines', which the operational division should handle, the 'detailed brief', which the building client division should be responsible for and 'maintaining good relations between the building client and the operations division', which the top management should see to.

The finding that separate actors exist within the building client makes it relevant to apply the theory of interdepartmental knowledge transfer (Kahn, 1996). Kahn (1996) distinguishes between interaction and collaboration. The single case study included in this thesis (Paper 2) showed that the interdepartmental cooperation between the operations division and the building client division in the specific case is based on interaction to a higher degree than collaboration. Thus, more attention is given to formal and structured activities across departments than activities aimed at developing mutual understanding and shared goals.

Despite the finding that only a few tools and methods are either technocratic or behavioural by default, building client organisations have a strong focus on codifying their operational knowledge and on finding efficient ways to store and transfer the codified knowledge. Design guidelines are one example. Here, the operations division develops written guidelines for new projects based on their experience. Top management approves the guideline documents, and the guidelines are subsequently pushed into the design processes of new building projects, thus following a technocratic approach. The identification of a strong focus on codifying operational knowledge is supported by previous research that found the technocratic approach to be dominant in engineering projects (Vianello and Ahmed, 2012). This does not align with other research noting that the behavioural approach is more suitable when an organisation works with customised and innovative products and the more units into which it is divided (Hansen *et al*., 1999; Hislop *et al*. 2018).

However, the knowledge that the guidelines contain is not always fully integrated into the design of new buildings despite detailed descriptions. Sometimes, deviations from the guidelines are discovered in design reviews by operational staff. One explanation for this is the phenomenon of information overload in building projects (Hansen *et al*., 2010; Winch, 2010; Jensen, 2012; Hall-Andersen, 2013). In cases of information overload, there is a risk of information drowning and never reaching the attention of the receiver (Kreiner, 2005). This may lead to suggestions of further documentation (Wulff *et al.*, 2000; Kollveit and Grønhaug, 2004;), e.g. a document on deviations from design standards, as suggested in one of the building cases of this study. This indicates a risk of a negative spiral reaction whereby more and more documentation is produced to ensure that operational knowledge is integrated into the projects. However, as project managers and design team staff have bounded rationality (Simon, 1991), they may not be able to take all the transferred knowledge into consideration in the design process, regardless of a comprehensive codification process.

Another possible reason for the lack of complete integration of design guidelines into the design is conflicting interests (Arditi and Nawakorawit, 1999; Lindkvist, 2018; Lindkvist *et al*., 2019). As will be described in the following answer to RQ 2, such conflicts can arise not only between the design team and the operation team but also between different subdivisions of the operations division.

In the SECI model (Nonaka *et al*., 2000) the process of creating new knowledge starts with socialisation followed by externalisation, which concerns e.g. development of descriptions etc. When written design guidelines are pushed from operation to design even before the design process of a specific new project has started, the mode of socialisation is skipped at least as a socialisation process involving staff from both operation and design. The socialisation might take place among operational staff before writing the design guidelines.

5.2 Answering Research Question 2 (RQ 2)

The second research question aims to gain further understanding of the integration of operational knowledge into design by looking at the difficulties facilities managers experience in new buildings. The question is as follows:

RQ 2: Which difficulties in the operation stage of new buildings are facilities managers concerned about, and how may these concerns affect the integration of operational knowledge into design, including the involvement of operational staff?

Facilities managers are concerned about a wide range of difficulties in new buildings. In contrast to the literature that defines building performance in terms of the discrepancy between the expected and the actual energy consumption of a building (Menezes *et al.*, 2012; van Dronkelaar *et al.*, 2016; Frei *et al.*, 2017; Coleman and Robinson, 2018; Gram-Hanssen and Georg, 2018; Lindkvist, 2018), this study introduces a facilities managers' typology of performance gaps. Moreover, the study identifies and ranks 35 specific FM difficulties' in new buildings in Denmark. Thus, facilities managers are indeed concerned about a wide range of difficulties in new buildings, and this complicates – and even jeopardises – the integration of operational knowledge into the design process of new buildings.

First, the difficulties are interrelated, as illustrated in the performance gap typology (see Figure 13). This means that actions to prevent one type of gap potentially influence other gaps, too. In relation to the integration of operational knowledge, it is very important to consider whether the suggestions or demands of one area of FM do not conflict with others. In other words, someone needs to evaluate and prioritise the necessary trade-offs among the suggestions and demands regarding operations.

The trade-offs need to be considered in relation to the specific project and its purpose. Considering trade-offs may result in the design team 'rejecting' operational knowledge if it is in conflict with other concerns. This rejection of knowledge can frustrate operational staff and give them the impression that ‘designers do not listen; they do as they please anyway’, which has been a repeated complaint from operational staff with whom I have discussed the topic of this research. Moreover, it may frustrate those who need to balance the parameters, which is expressed in another commonly heard complaint, namely that operational staff are too demanding: ‘they would ask for golden taps if they could’, especially if they are given a ‘strong voice’ as recommended in the literature (Jauntzen, 2001; Jensen, 2009, 2012).

Thus, as mentioned in the answer to RQ 1, it is not only a question of conflicting interests between the project team and the FM team, which has been identified in previous research (Jensen, 2012; Whyte *et al*., 2016: Lindkvist, 2018); conflicting interests among different FM areas are also an important issue. An increase in conflicting interests adds complexity to the topic of knowledge transfer (Carlile, 2004) as knowledge developed in one area generates negative consequences in another. In terms of building projects, conflicting interests call for someone to balance and, if necessary, to prioritise conflicting demands and suggestions from the FM staff involved, including staff from the operations division. If trade-offs between the gaps are not evaluated, involving operational staff can be counterproductive.

This shows that involving FM in design processes is not as straightforward a task as is assumed in the literature. The variety of FM contributions to the design process is therein described, but description of the potential conflicting interests within FM is limited (Jauntzen, 2001; Jensen 2012; Adeyemi *et al*., 2019; Fatayer *et al*., 2019). Neither FM nor operations is not a well-defined sender of operational knowledge.

The literature places, as mentioned above, a strong emphasis on the energy performance gap. However, the findings of this study indicate that energy is often not a fatal performance gap for FM in new buildings. There has been great political focus on energy performance due to the trending global political agenda (EU, 2016). This possibly explains why this type of performance has received much more attention in research than in practice.

Besides the performance gap typology, the study outlines 35 specific difficulties that FM practitioners can experience in new buildings, spread across six categories. The 35 difficulties are ranked based on the results obtained from a questionnaire distributed among practitioners on a scale from ‘most often experienced’ to ‘least often experienced’. Among the most-often-experienced difficulties, according to the questionnaire respondents, are getting digital documentation from a project, such as O&M documentation and drawings, having unexpectedly high energy consumption due to a lack of technical installation commissioning and experiencing poor thermal indoor climate.

In looking at both the performance gap typology and the 35 specific difficulties, it becomes clear that even though involving FM staff may be helpful, it does not singlehandedly prevent a performance gap or FM difficulty from appearing. An example of this is the challenge of getting digital documentation, such as O&M manuals and correct drawings, from a project. This is identified in this study as an often-experienced difficulty, which is supported by the literature (Tan *et al.*, 2018). Involving operational staff in the design process may ensure that the correct requirements for the documentation are put forward at the right time and that the project actors are motivated to deliver the required documentation (Whyte *et al*., 2016). However, if staff members of the design team or the contractor team lack the skills necessary to develop or coordinate the required documentation, then involving operational staff will not solve the problem.

The literature on the energy performance gap reaches a similar conclusion, where causes for the energy performance gap include uncertainty in design and modelling, occupant behaviour and poor practise in operations (van Dronkelaar *et al.*, 2016). Thus, bridging performance gaps in new buildings is not solely a question of integration of knowledge from operation into design.

5.3 Answering Research Question 3 (RQ 3)

The third research question concerns the comparison of building and large ship projects, and it aims to find out what can be learnt about the integration of operational knowledge into design:

RQ 3: What can be learnt about the integration of operational knowledge into design by comparing projects for buildings and large ships?

The comparison of the integration of operational knowledge into design across building and ship projects yields a number of important findings. This proves the relevance of the comparison and gives reason to believe that further comparison between the two potentially can yield even more interesting findings. The following subsections (5.3.1–5.3.4) provide an answer to RQ 3. This is followed by reflections on the lens of knowledge transfer.

5.3.1 General conditions & tools and methods.

The specific building and ship cases studied throughout this study and the projects described by the interviewees in its different methodological steps show that both building and ship projects come in many shapes and sizes and, thus, have various general conditions. These general conditions play a role in how operational knowledge is integrated into the design process. Clients within both industries can, for example, be either public or private, build to own or build to sell, have a tripartite building client organisation (see Figure 11) and can use either internal or external design teams and consultants. However, a few distinct differences exist. As an example, the educational background of naval architects is different from that of building architects. Naval architects typically have the educational background of engineers.

A general condition of a project is also whether the new facility – building or ship – is going to either 'stand alone' or be part of a larger portfolio of buildings or ships. In the latter case, the need for the transfer of knowledge from operations to design increases in order to make the new facility 'fit' into the portfolio to ensure its ease of operations. This is a condition shared by projects for buildings as well as large ships.

Another shared general condition is the organisation of the client company in regard to the tripartite building client (see Figure 11). Large organisations are often organised in accordance with the tripartite building client scheme, whilst smaller organisations, with few new projects, are not. I will later elaborate on the role played by the affiliation of the building client's project manager in the integration of operational knowledge into design.

A comparison of the tools and methods identified in the two types of projects shows that similar tools and methods are used, although some have slightly different names and content. Examples of similar tools include LCC (buildings)/total cost of ownership (ships), design review by operational staff and study trips. Commissioning is used in both industries but used very differently. In one of the building cases, it functions as an overarching tool to manage the process of involving operational staff, from early design to handover and testing the technical systems. In contrast, the interviewees from the shipbuilding industry describe commissioning solely as a tool for testing that all systems function together as intended towards the end of the construction stage. Here, commissioning starts a few months before the end of the construction stage and ends by the handover. Consequently, I see commissioning within shipbuilding to be a quality control system and not a tool used to transfer knowledge from operations to design. However, when used by the building industry, the concept is broadened and can, to some extent, be identified as a method for integrating operational knowledge into design. The development of operational budgets in the design process is in the investigated cases only taking place in the ship projects.

On-boarding is an example of a tool that is used in some ship projects that can potentially serve as inspiration for building projects. On-boarding is, on the one hand, a tool through which members of the sea crew team are on-boarded to the project team on land. The opposite process also occurs, on the other hand, by which design staff is on-boarded to the sea crew team – however, this is done for a shorter period of time. Both variants of on-boarding are examples of tools based on a behavioural approach (Earl, 2001; Vianello, 2011) to knowledge transfer in which the members of one unit are moved to another unit (Argote and Ingram, 2000). The purpose of moving operational staff to the design team is to alter the knowledge and performance of the design team, the receiving unit. In the opposite case, i.e. when design staff is moved to the operational team, the purpose remains – to change the knowledge of the design team. They are still 'receivers' even though they are now visitors rather than hosts. No examples of on-boarding design staff members to operation teams during the design process of *buildings* have been identified in either the literature, the expert interviews or the case studies.

5.3.2. Technocratic and behavioural approach & tools and methods.

The involvement of operational staff in the investigated building cases was extensive, which stands in contrast to both previous research (Jensen, 2009; Lindkvist, 2018) and to what I often am told by operational staff. In the investigated ship cases, operational staff was less involved in the design process, whereas the project manager in the ship cases considered operations continuously throughout the design process. To mention one example, the project manager developed and maintained operational budgets throughout the design process. Despite extensive involvement of operational knowledge in the building projects, project managers of these cases did not develop operational budgets in the design stage.

As for building projects (RQ 1), the tools and methods for integrating operational knowledge into the design of large ships are used in ways that are based on either the technocratic or behavioural approach (Earl, 2001) or a combination of the two. In both building and ship projects, the approach is generally determined by the organisations and individuals who implement and use the tools or methods rather than by the tools or methods themselves.

Design review by operational staff is a tool that, in some cases, is based on a technocratic approach, meaning that codified knowledge is primarily exchanged via spreadsheets and project documents. In other cases, the review by operational staff represents a combination of both codified and personalised knowledge and, thus, leans towards the behavioural approach. An example of a method that is based on the behavioural approach is given in one building case. Here, design review was performed ad hoc and continuously by one operational staff member, who was moved, in a part-time capacity, to the design team. This is the building equivalent of the on-boarding tool identified in ship design.

In regard of the SECI model (Nonaka *et al*., 2000), the knowledge conversion process is described as a spiral movement starting with socialization (Martin and Root, 2009; Hislop *et al*., 2018; Kahrens and Früauff, 2018). On-boarding can to some extend be seen as an example of socialisation, thus according to Nonaka, an important starting point for successful knowledge sharing.

If measured by how much knowledge is *transferred*, the building case in which the review – and other tools and methods – follows a technocratic approach is definitely the most successful one. However, the literature suggests that knowledge transfer is not to be measured by how much knowledge is transferred but rather through an increase in performance at the receiving end (Argote and Ingram, 2000). Measurement of design staff performance or performance of the new building or ship was not among the objectives of this study. However, the study did not find indications that operations were any less considered in the design process of the cases with a low degree of codified operational knowledge. Other aspects, such as the project manager's affiliation and matters of concern (Latour, 2004; Kreiner, 2010), appeared to play a more important role.

5.3.3 Project managers need incentives to integrate operational knowledge

If a project manager has incentives to consider operations in the design process, then he or she will do so regardless of the limited use of tools and methods, including involving operational staff. This is supported by literature, wherein it is stated that 'participants will mobilize resources, knowledge and practices to meet their own need' (Elmualin *et al*., 2009, p. 92). Furthermore, 'The integration of facilities management knowledge in problem solving to a high degree depends on the architects' and engineers' interest and capability to do so' (Hansen and Damgaard, 2012, p. 280).

Referring to the literature, incentives can be either intrinsic or explicit. Intrinsic incentives appear to be more important for integrating tacit knowledge (Zuo *et al.,* 2013). As operational knowledge is, to a large extent, tacit (Hansen *et al.,* 2010), the literature supports this study's suggestion that getting operations into the matters of concern to project managers is an efficient way to get them to consider operations in design without, necessarily, the extensive involvement of operational staff.

I find the technocratic approach to be suitable for transferring knowledge to, for example, describe a portfolio of specific knowledge. However, for design teams to 'pick up' knowledge and, furthermore, to seek knowledge on operational matters themselves, the behavioural approach is needed, with a focus on getting operations into the matters of concern to the project team. This is supported by researchers of ship design, suggesting that designers need to develop a 'sea-sense' (Lurås and Nordby, 2015). In order to develop this sea-sense, researchers find that designers need to 'be out there' (Gernez, 2019b), e.g. be on-boarded to the operational team for a period. Kreiner reaches a similar conclusion from a study of a product development project of a digital hearing instrument (Kreiner, 2002), in which two business units collaborate on a design. He finds an example where one unit is extremely motivated to fulfil a task required by another unit. He concludes that this is not because the requiring unit had made an explicit, detailed request, which they had not, but because they had managed to 'trigger' or motivate the unit to stretch their capabilities to fulfil the need of the other unit.

Getting operation into the matters of concern to the project manager does not replace tools and methods, including direct involvement of operational staff members. Instead, it aims to increase the effectiveness of using the tools and methods as well as efficiency by limiting the waste of transferred knowledge. This is supported by previous research, which recommends a combination of the two approaches, noting that both technical tools and social interaction are needed to transfer knowledge in projects (Le and Brønn, 2007; Jensen, 2012; Lindkvist *et al.*, 2019).

5.3.4 Differences between operational and project staff as barrier and opportunity

Previous research has accounted for differences between operational staff and design staff. The two have different perspectives on the projects they are involved in, different identities and knowledge bases and, typically, different educational backgrounds (Jauntzen, 2001; Johnstone *et al.*, 2007; Jensen, 2012). This has been described as a barrier to transferring knowledge from one to the other. To overcome this barrier, research has suggested that operational staff should acquire competences similar to those of the design team in order to 'get a stronger voice' and to be 'taken seriously' (Jensen, 2009, 2012).

In one of the building cases in the multiple case study, the operational department was represented by a team of so-called asset managers that could be categorised as knowledge brokers (Vianello, 2011) between the project team and the operational team and, thus, as an 'intra-team' (Kahn, 1996). This team was employed solely to care for operational issues in new projects, including commissioning. The intra-team employed staff with skills similar to those of the project team, aiming to bridge differences and ease knowledge integration - a strategy supported by the knowledge management literature (Brown and Duguid, 2001; Carlile, 2004; Vianello and Ahmed, 2012; Hislop *et al.*, 2018). I found that the intra-team did, indeed, have a strong voice in the design process. 'Voice' is perhaps not the appropriate term, as the communication was mostly based on large amounts of codified knowledge in accordance with management-approved procedures. This included detailed design guidelines developed and maintained by the intra-team, on which the designers were expected to base their design proposals. As such, the operational staff, represented by the intra-team, were, in my interpretation, actually designing.

In the three ship cases, the strategy employed was opposite to that of the building cases. Here, the project manager had skills similar to those of the operational team; in fact, in one of the cases, the project manager was actually the deputy director of operations. Thus, operational staff naturally had a 'strong voice' in the design process. However, the study shows that in these projects, there was limited integration of knowledge beyond the boundaries of operations, such as user experience or aesthetics.

Based on this, I find that assimilating the operations team and project management or design teams may give operations a 'strong voice' and ease the integration of operational knowledge. Yet, I speculate whether there is a risk that it might jeopardise other concerns in these projects.

5.4 The lens of knowledge transfer

Previous research describes a lack of building performance that can be seen as a result of insufficient knowledge transfer – or feedback/feed-forward – from operations to design (Cohen *et al.*, 2001; Way and Bordass, 2005; Le and Brønn, 2007; Jensen, 2009; Kristiansen, 2010; Jensen, 2012; Meng, 2013; Adeyemi *et al.*, 2019). Based on that, this study draws on the research field of knowledge management, and in particular, knowledge transfer, which is applied as a lens through which the phenomenon is studied.

Different theories and models from the field of knowledge management have provided me with valuable insight into the topic, but more – or others- could have been applied. An alternative focus on the design processes and the tools and methods implemented could have been placed on working systems (Conceição *et al*., 2015), communities of practice (Jørgensen *et al.*, 2019), activity theory (Lu *et al.*, 2018; Saridaki and Haugbølle, 2019) and actor network theory (Berntsen and Seim, 2007). The present study was not guided by a single overarching theory. However, the two approaches that I identified from both the knowledge management literature and the literature on knowledge transfer in engineering projects – the technocratic and the behavioural approaches – formed a basis for my analysis and interpretations.

The SECI model has been applied to studies of construction management (Martin and Root, 2009), thus assumingly relevant to this study. I found it relevant in terms of distinguishing between different modes of knowledge conversion. However, I found applying the SECI model to my study less fruitful than expected. Especially two issues challenged the application of the model. First, the SECI model indicates different steps one can take sequential over time to develop new knowledge. Even if such steps potentially could happen in few minutes, I found that they were happening at the same time, in parallel, rather than sequential, thus challenging to identify and analyse in the study. Second, the SECI model is limited concerned with conflicting interests (Carlile 2004; Hislop *et al*., 2018). Similarly, the challenges – and opportunities – different cultures brings to knowledge sharing is also limited described (Kahrens and Früauff, 2018). Conflicting interests and diverse cultures between design and operational staff are identified as important factors in the process of integrating operational knowledge in design (Damgaard and Erichsen, 2009; Jensen, 2012). Nevertheless, the SECI model could potentially have added more continuity to analysis and interpretations throughout my study.

The lens of knowledge transfer offers the opportunity to study not only which tools and methods enable operational considerations in design but also *how* and under which conditions tools and methods are used. As such, the lens assisted me in developing new knowledge on the topic.

However, the problem of lack of building performance is not, according to my findings, caused by the lack of integration of operational knowledge alone. Thus, increased knowledge transfer does not singlehandedly prevent performance gaps in new buildings. Consequently, the lens falls short of providing a complete answer to the problem of performance gaps and FM difficulties. Other relevant lenses could have been risk management or project management.

Some of the interviewees expressed that they had not considered the topic as a matter of knowledge transfer before I introduced it as such. It was obvious that for some interviewees, it took a while before they truly understood what I was looking for. However, once they observed their own actions in the light of knowledge transfer, they were able to mention many tools and methods. They also mentioned initiatives that were not directly linked to transferring any codified knowledge, such as shared breakfast events or other events aimed at creating relationships and team spirit. Such events are based on a behavioural approach to knowledge transfer. Based on that, I find there is reason to believe that applying the lens of knowledge transfer can assist practitioners in considering how technocratic and behavioural approaches complement each other in furthering not only the aim of transferring knowledge but also that of integrating knowledge from operations into design.

6. Conclusion

In this chapter, I draw conclusions based on the main findings across the research papers and research questions to answer the main research question. Below, I discuss the findings of this thesis in relation to the literature and account for the contributions of the present study. Subsequently, I discuss the findings in relation to practice. Finally, I account for limitations and provide suggestions for further research.

6.1 Answering the Main Research Question (MRQ)

The purpose of this study is to develop knowledge on how operational knowledge is integrated into the design of buildings in comparison with ship projects. In the previous chapter of this thesis, I answered three sub-research questions which lead to the answer to the main research question, which is as follows:

MRQ: How is operational knowledge integrated into the design process of buildings in comparison to that of large ships, with the aim of improving facility performance?

The answer to the question is described in the following six subsections (6.1.1–6.1.6).

6.1.1 Comparing projects for buildings and large ships is relevant

The ambition to integrate operational knowledge into design is relevant in the design of both buildings and large ships. The similarities make it possible to compare the two, while the differences make the comparison informative. Despite the similarities, no prior research has compared how operational knowledge is integrated into the design of these two types of projects.

The expert interviews, workshops and case studies indicate that there are huge differences among different building projects as well as among different ship projects, indicating that the differences might be just as huge within each type as they are between building and ship projects in general.

6.1.2 Tools and methods & general conditions

This study showed that many tools and methods to integrate operational knowledge into building design exist and that many of them are implemented in practice. The responsibility for the implementation of tools and methods is distributed among three main actors within the building client organisation: the top management, the building client division and the operations division. Despite differences in terminology and use, there is an overlap of the tools and methods used in building and ship projects. Examples include LCC and design review by operational staff. Commissioning is an example of a method for which the name is identical, but the actual use is very different in projects for buildings and large ships. In the building cases investigated in this study, many resources went into enabling knowledge integration from operations into design, and operational staff was extensively involved in the design process. In the ship cases, fewer resources went into enabling knowledge integration from operations into design.

6.1.3 A technocratic or a behavioural approach

The integration of operational knowledge into the design process builds on either a technocratic or a behavioural approach – or a combination of the two (Earl, 2001; Vianello, 2011). The technocratic approach is based on the assumption that knowledge can be codified, stored and subsequently applied to a new context. The behavioural approach considers knowledge to be mostly tacit; thus, it is impossible to codify and store and must be derived from the knowing person.

This study shows that it is often not the tool or method itself but rather *how* it is used in an organisation or project that is based on either a technocratic or a behavioural approach (Earl, 2001; Vianello, 2011). In some projects, the tools and methods to integrate operational knowledge are used primarily based on a technocratic approach, resulting in a large amount of documents and spreadsheets. However, the study does not find that this guarantees that the knowledge is well integrated into the design process. On the contrary, the overload of information in design processes implies a risk that some of the codified and transferred knowledge will be wasted as it will never catch the receivers' attention. Moreover, in the building cases, the findings of this study indicate that a negative spiral reaction can occur, wherein more and more involvement of operational staff is needed to ensure high facility performance.

6.1.4. Facilities managers have different concerns in building projects

The purpose of integrating operational knowledge into the design process, using tools and methods, is to ensure that the actual performance of a facility in operation is optimal and prevent performance gaps from occurring. The literature defines the performance gap as the energy performance gap (Menezes *et al.*, 2012; van Dronkelaar *et al.*, 2016; Frei *et al.*, 2017; Coleman and Robinson, 2018; Gram-Hanssen and Georg, 2018; Lindkvist, 2018), whereas this study presents a facilities managers' typology of performance gaps consisting of 12 gaps, including the energy performance gap. The typology, in contrast to the narrow definition of the performance gap in the literature, broadens attention to encompass the interrelationship between the gaps. Moreover, the findings show that while the energy performance gap is important, it is not necessarily the most important gap to prevent in all types of projects. The hierarchy of types of performance gaps depends on the specific project and its purpose.

The FM staff involved in design processes are often specialised in one or a few FM activities, such as cleaning or maintenance. This poses a challenge in terms of involving operational staff as suggestions or even demands from the involved operational staff must be considered in relation to other parameters. Examples of such trade-offs are provided by actors in both building and ship projects. The interrelation and hierarchy of gaps need to be carefully considered in each project, building or ship. If not, the integration of operational knowledge, including involving operational staff, can be counterproductive.

Furthermore, regarding buildings, 35 specific difficulties experienced by facilities managers of new buildings in Denmark are identified. Of the 35 difficulties, those most often experienced in new buildings in Denmark are as follows: getting proper digital documentation from the projects to FM (O&M documentation and drawings), unexpectedly high energy consumption due to lack of commissioning of technical installations and difficulties concerning indoor climate.

To prevent the reproduction of the same difficulties and improve facility performance, building clients and their consultants need to consider which actions are needed to ensure that the difficulties most experienced are not repeated in new projects. Applying the tools and methods to integrate operational knowledge identified in this study may be helpful. However, optimising facility performance is not solely a problem of knowledge transfer from operations to design.

6.1.5 Affiliation of project managers and matters of concern to them play a role

Furthermore, the study shows that general conditions play a role in how operational knowledge is integrated into the design process. Most significantly, the affiliation of the building client's project manager and matters of concern (Latour, 2004; Ripley et al., 2009; Kreiner, 2010; Brodersen and Pedersen, 2019) to him or her play a role. The present study shows that when the project manager has a short-term interest in the project and operations *are not* a matter of concern to the project manager, many tools and methods are employed in the design process to ensure that operations are taken into consideration. On the contrary, when the project manager has a long-term interest in the project and operations *are* a matter of concern to him or her, operations are taken into consideration throughout the design process, even by the use of very few resources.

In other words, if project managers have intrinsic incentives to consider operations in the design process, they will do so regardless of whether the involvement of the operational staff is limited. On the contrary, if project managers do not have intrinsic – and possibly external – incentives, then many resources are needed to ensure that operations are considered in the design process.

This challenges the underlying assumption in the literature (Jensen, 2012; Adeyemi *et al*., 2019) – and, possibly, among practitioners as well – that the more knowledge is transferred, the more operations are taken into consideration, resulting in improved facility performance.

6.1.6 On-boarding is possibly a tool to place operations into the matters of concern to project managers

On-boarding is a tool from ship projects that can potentially serve as inspiration in building projects. On-boarding is, on the one hand, a tool through which members of the sea crew team are on-boarded to the project team on land. The opposite process also occurs, on the other hand, whereby design staff is on-boarded to the sea crew team. However, the latter is done for a shorter period. Both variants of on-boarding are examples of tools based on the behavioural approach (Earl, 2001; Vianello, 2011) to knowledge transfer, in which the members from one unit are moved to another (Argote and Ingram, 2000). Specifically, the on-boarding of design staff to operations is interesting. Hence, the purpose is not so much to transfer knowledge directly from operations to design as it is to establish the design team staff's 'sea-sense', thus placing operations among their matters of concern.

In sum, less focus should be put on knowledge *transfer*, whereby a large amount of knowledge – often explicit – is stored and transferred from operations to the design process. Instead, clients need to figure out how to place operations among the matters of concern to project managers and designers, without jeopardising other concerns. Having operations as a matter of concern 'triggers' project managers to *integrate* operational knowledge and, thus, to increase the effectiveness and efficiency of the many available tools and methods.

6.2 Contribution to the literature

This thesis contributes to the literature on knowledge transfer from operations to design, primarily in the sphere of building projects and, to a lesser extent, shipbuilding projects. The thesis also contributes to the literature on performance gaps and difficulties in new buildings. The theoretical background concerning knowledge management, including knowledge transfer, bounded rationality and matters of concern, serves as the framework for this study's analysis and interpretations.

The study shows that it is relevant to compare projects for buildings and large ships in relation to the integration of operational knowledge. The two industries have common challenges in integrating operational knowledge, which make their comparison relevant. This study shows that the two types of projects have more in common than previous research suggests (Knotten et al., 2016). One example is the relevance of the tripartite building client developed in this study to both building and ship projects. The use of a tripartite building client introduces nuances to the literature discussion, which often mentions 'the building client' as a unity or as one person (Jensen, 2009; Fatayer *et al*., 2019). Moreover, the study shows that the affiliation of the project manager in regard to the tripartite building client plays a role in the integration of operational knowledge.

The study also contributes to the literature through the identification of relevant tools and methods to enable the integration of operational knowledge into building design, as well as by identifying and comparing tools and methods in large ship projects. Moreover, the study contributes by showing that tools and methods are used very differently in various projects and organisations, and the individual ways of using the tools and methods can be based on either a technocratic or behavioural approach (Earl, 2001; Vianello, 2011) – or a combination of the two.

Moreover, the thesis contributes to the literature on performance gaps and building performance by providing a typology (Cornelissen, 2017) of 12 performance gaps and by identifying 35 specific difficulties that facilities managers can experience in new buildings in Denmark. The term *performance gap* is defined in the literature as the discrepancy between expected and actual energy consumption (Menezes *et al.*, 2012; van Dronkelaar *et al.*, 2016; Frei *et al.*, 2017; Coleman and Robinson, 2018; Gram-Hanssen and Georg, 2018; Lindkvist, 2018). Thus, the typology of performance gaps from an FM perspective contributes to the literature by offering an alternative and competing understanding and definition of the term. Furthermore, the literature has so far identified conflicting interests between project and FM staff (Arditi and Nawakorawit, 1999; Lindkvist, 2018; Lindkvist *et al*., 2019). This study extends that discussion by showing – based on the performance gap typology – that conflicting interests can occur among different aspects of FM. In terms of the 35 difficulties, it contributes by extending the existing literature.

The case studies of building projects revealed that operational staff are extensively involved in the design process of these specific cases. This finding contradicts the literature, which reports a low degree of involvement of operational staff in building projects (Jensen, 2012; Kalantari *et al.,* 2017; Lindkvist, 2018) and yields a more precise conclusion based on the literature together with the contribution of this thesis that the level of involvement of operational staff varies across building projects.

However, the study shows that the affiliation of the project managers of new projects and their matters of concern play an important role in regards to integrating operational knowledge. When operations are a matter of concern to the project manager – thus giving him or her incentives – operations are considered throughout the design process, even with a low degree of involvement of operational staff in the projects.

6.3 Contribution to practice

It is not new that practitioners aim to bring knowledge on building operations into projects for new buildings with the aim of improving the performance of new facilities. This thesis contributes to that aim, as described below.

6.3.1 Identification and comparison of tools and methods

The study introduces the idea of a tripartite building client, consisting of top management, the building client division and the operations division (Figure 11). A successful integration of operational knowledge depends on actions from all three parties. A list of relevant tools and methods to integrate operational knowledge is provided. The list is organised according to which of the three parties should be responsible for the tool or method (Table 13). Building client organisations can use this list to discuss which initiatives they wish to implement and which party is responsible for the initiative. However, it is important to note that this study shows that tools and methods are used very differently. Hence, each organisation – client or consultant – needs to define its own version of a tool or method.

The study further shows that most tools and methods can be implemented based on a technocratic approach, a behavioural approach (Earl, 2001; Vianello, 2011), or a combination of the two. The technocratic approach does, in some building cases, result in a large amount of documentation, e.g. spreadsheets and documents. Building clients can implement and use most tools or methods in either a technocratic or behavioural approach.

By comparing how knowledge is integrated into the design of buildings and large ships, it was found that many tools and methods are used in both types of projects. One exception is 'on-boarding', which is (mostly) used in projects for large ships and can serve as inspiration for building clients. On-boarding is a tool which, to a large degree, is based on a behavioural approach.

6.3.2 Performance gap typology and FM difficulties in new buildings – checklists

This study makes an additional contribution of a typology of performance gaps from an FM perspective (see Figure 13). I presented this typology to a group of people in a network for building commissioning. One of them, whom I know is a very experienced commissioning manager, raised her hand and said that the typology could be very useful in the early design stages to facilitate discussions on 'what is actually most important in this particular project'. It could thereby act as a support tool for those who need to consider trade-offs between different performance parameters. In another presentation, an experienced project manager said that project managers balance these parameters all the time; however, they seldom have an explicit discussion about it. The typology can be used as a discussion scheme to raise the awareness of both operational staff and project staff about the trade-offs and hierarchy of performance parameters from an FM perspective.

Moreover, this study identified 35 difficulties that facilities managers can experience in new buildings in Denmark. I encourage both operational staff, project managers and design staff to look through the 35 difficulties (in particular, those most often experienced), both at the beginning and continuously throughout a new project, asking: 'What have we done to ensure that the difficulties others experience so often will not appear in this specific project?' I am certain that in many cases, the answer will be to increase the quality of the project in the spheres of management, design or construction. Integrating operational knowledge, including involving operational staff, does not alone prevent the difficulties, although it certainly can be helpful. The 35 difficulties are included in this thesis in Table 15.

6.3.3 Project managers' affiliation and matters of concern play a role.

The study shows that in the cases where operations were a matter of concern for the project manager, operations were considered throughout the project with the use of only limited resources. On the contrary, in the projects in which operations were not a matter of concern to the project manager, much effort and many resources went into ensuring that operations were considered.

One tool that could possibly help introduce operations into the matters of concern to the project team is what I have called 'on-boarding'. It comes in two variants – one in which members of the operational team are onboarded to the design team and one in which members of the design team are on-boarded to the operational team.

The first variant, the on-boarding of operational staff to the design team, is found in one of the building cases. The lead architect described this in a very positive manner and explained how she consulted the on-boarded operational staff member to get advice on various topics, either in formal meetings or by informally posing a question across the desk in their shared open office. As such, the operational knowledge was accessible when she needed it, rather than being front-loaded at the beginning of the project. In this way, a possible waste of knowledge, due to information overload, can be reduced.

The other variant, the on-boarding of design staff to the operational team, was described by my interviewees from the shipbuilding industry and in the ship design literature, but it was not implemented in any of the examined cases. However, according to the literature, its purpose is not to transfer large amounts of knowledge from operation to design; rather, the purpose is to shape the 'sea-sense' of designers. To do so, they are on-boarded a ship for a period of time, e.g. one or two weeks, to experience operations, talk to the operational staff, study specific operational tasks and so forth. This method is based on a behavioural approach.

I recommend that building clients test whether such an on-boarding of project managers and members of the design team to the operational team can place operations among the matters of concern to the design team, thus increasing the effectiveness of the tools and methods applied to integrate operational knowledge into design. Moreover, this practice could enable building clients to find ways to reduce waste of knowledge by making knowledge accessible 'on demand' on the initiative of the project manager rather than through front-loading extensive codified knowledge into the design process.

6.3.4 Differences between operational staff and project staff as barrier and opportunity

This study describes two opposite strategies for giving operations 'a stronger voice' in design processes. One is to establish an intra-team of knowledge brokers with the aim of linking operations and design. Such brokers do typically have skills similar to the project team, e.g. knowledge on procurement strategies, legislation etc. The other, which was identified in the ship cases, is to select a project manager with operational skills.

The study poses the question of whether these strategies, which I find can be characterised as assimilation, are a barrier to increased innovation in the projects. The study does not answer this question. However, I encourage practitioners to try out alternatives in order to fully exploit the potential of innovation through combining the two bodies of knowledge rather than assimilating them into one, thus, focusing less on giving operations a strong voice in design processes and more on giving operations a 'voice of their own'.

6.4 Limitations and opportunities for further research

As with any research, this study is not free of limitations. In the following subsection, I point out some of the limitations and suggest agendas and opportunities for further research.

The present research contributed to the literature a typology of performance gaps from an FM perspective. The types are interrelated and their hierarchy determined by the specific project and its purpose. Further research is needed to gain knowledge on the interrelations. In my opinion, increased integration of operational knowledge does not singlehandedly prevent all gaps. Consequently, more research is also needed on what causes the different gaps in order to develop recommendations on ways to bridge them.

The questionnaire survey gathered 35 FM difficulties in new buildings. Furthermore, the most-often-experienced difficulties were identified. Further research is needed on both the causes and consequences of the difficulties. Moreover, the questionnaire could be repeated in other countries or, perhaps, even in the shipbuilding industry.

The need to 'trigger' or inspire project team members to seek operational knowledge when they need it, as an alternative to knowledge front-loading, needs to be further confirmed. First, further research should investigate whether the effortless integration of operational knowledge into the ship cases is similar in building cases if the project manager is experienced with operations. Second, further research is needed on *how* to trigger the project team. This thesis refers to studies on human factors and ergonomics studies and studies on occupational health and safety management (Paper F) as sources of inspiration. However, further research is needed to see whether the findings from such studies apply to the integration of operational knowledge into design as well.

The findings of this study suggest that on-boarding members from the project team to the operational team is a way to shape the 'sense of operations' of project team members. However, the study does not offer any specific suggestions on how this could be implemented in practice. Furthermore, it does not present any examples of cases in which this has proved to be the most efficient way to 'trigger' the integration of operational knowledge in design. Further research is needed to clarify this matter. Additionally, I focused on internal incentives, such as matters of concern. Further research should focus on external incentives, too. For example, financial incentives are possibly powerful 'triggers'.

Moreover, the study touches only slightly on knowledge brokers (Vianello, 2011) or intermediaries (Lindkvist *et al.*, 2019) between the project team and operational team. In both building cases described in Paper F, an 'intra-team' (Kahn, 1996) was established. More research is needed on the advantages and disadvantages of the use of an intra-team. Furthermore, the findings on the performance gap typology show that operational staff potentially have conflicting interests. I am curious to see what role a knowledge broker plays in relation to this, as he or she would also be influenced by his or her own matters of concern.

In one of the building cases, the involvement of operational staff was heavily based on a technocratic approach, resulting in a codification strategy (Hansen *et al.*, 1999; Lê and Brønn, 2007), in which large amounts of documents and spreadsheets were produced. The operational staff front-loaded all this codified knowledge into the project in its early stages and then repeatedly checked, whether it was being sufficiently integrated into design proposals. Not only was this time-consuming for both the project team and the operational team, but it also seemed to instil a 'laziness' within the design team. The operational staff in the same case suggested their further involvement when asked what would improve facility performance. I find this interesting because the involvement of operational staff in this case is the most extensive that I have yet seen. I speculate whether there is a risk of creating a negative spiral whereby increasing FM staff involvement is needed as the design team becomes less and less motivated to consider operations on their own initiative due to the strong involvement of operational staff. Indications of what could be characterised as 'over-involvement' have not yet been addressed in the literature on the integration of knowledge into design. I recommend future research to investigate this 'over-involvement' of operational staff in design process.

The findings of this study show that tools to integrate operational knowledge into design are primarily used in the design stage, which is in accordance with recommendations from research. However, findings from the case study show that, actually, design takes place in stages other than the design stage. An example of this is when contractors are responsible for the detailed design of (e.g.) technical installations. Respondents of both building and ship cases explained that detailed design is often decided on at the construction site by those who build and only in some cases through cooperation with the client's site inspectors. This indicates that, besides project managers and designers, contractors also need to be encouraged to consider operations in design.

Furthermore, previous research and some of my interviewees suggested that 3D models, particularly together with virtual reality tools, could make the integration of knowledge into construction projects easier (Bouchlaghem *et al.*, 2005). Although I share their optimism about such tools and methods, I did not find them used for the purpose of integrating operational knowledge in any of the cases in the present study. 3D models did, however, serve as a tool to transfer knowledge within the design team across disciplines in some cases. Moreover, in the hospital case, virtual reality was used at an experimental level by a group of students to give users and stakeholders an impression of how the new hospital would look. I agree that 3D models and virtual reality tools hold the potential to reveal operational difficulties already in the design stage, where changes are easier to make. However, the cases selected for this study did not give me the opportunity to investigate this. Thus, I suggest that further research investigate the use of BIM and virtual reality to integrate operational knowledge into design.

Finally, research on the integration of ergonomic knowledge in design (Hall-Andersen, 2013) appoints the design team members to be gatekeepers of knowledge integration, thus playing a very important role. I focused on the building client, based on the literature, but also noticed that many decisions were made 'at the designer's desk' rather than in meetings with the project manager. Consequently, I speculate whether it should be the designers who need to be 'triggered' to take operations into consideration while designing. I hope researchers will investigate this in the future.

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Appendices

Appendix 1. Paper A

Appendix 2. Paper B

Appendix 3. Paper C

Appendix 4. Paper D

Appendix 5. Paper E

Appendix 6. Paper F

Appendix 7. List of other publications

Appendix 8. List of presentations

Appendix 9. Co-author statements

Appendix 1

Paper A

DTU Library

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Initiatives to integrate operational knowledge in design: a building client perspective

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Abstract

Purpose: This paper aims to focus on deliberate actions by the building client to integrate knowledge of facilities management, in particular building operation, in design and construction of sustainable facilities. Examples of current practices are studied to answer the questions: Which initiatives to enable operational friendly and sustainable buildings are currently used by building clients in Denmark, which initiatives could be appropriate to use in the future, and which parties are in the best position to implement the various initiatives?

Design/methodology/approach: The study is a hermeneutic multi-method study, which consists of a review of former research, a case study and a survey. It starts with theoretical background based on earlier research with the aim to identify initiatives to ensure the use of operational knowledge in building design. Hereafter the paper present, analyse and discuss two studies: A case study of current practices at a university campus organisation and a survey of five swimming facilities. All cases are from Denmark.

Findings: 31 initiatives to enable use of operational knowledge in building design were initially identified. In the case study, 11 additional initiatives were found. The case study and the survey of swimming facilities show different degrees of implementation, varying from 18 to 31 initiatives implemented. However, the studies show that introducing the initiatives is not sufficient; it takes deliberate actions to get the initiatives well implemented. Within the building client organization, three main actors should care for implementing the initiatives: Top management, Building client division and Operation division.

Originality/value: Research-based literature on practices in relation to knowledge transfer from operation to design is limited. This paper provides insights into deliberate efforts on transferring knowledge from operation to design among Danish building clients.

Keywords: *Sustainability, Facilities management, Energy efficiency, Knowledge transfer, Building design, Performance gap.*

Introduction

A large number of newly built facilities do not live up to the expected performance at the time they are taken into use (Due and Stephensen, 2012; Hansen and Damgaard, 2012). In concerns of energy consumption, the literature describes a reliability gap between the calculated and the actual energy consumption (Wilde, 2014; Corry, 2015; Way and Bordass, 2005; Ornetzer et al., 2016). In addition to energy efficiency, other aspects of building performance have been recognized to be deficient: lack of functionality, poor indoor climate, difficulties in operation and maintenance, and poor cleaning possibilities. In other words, there is a gap between expected and actual performance, and in a broad perspective.

The reduced performance in facility operation persists until changes can be administered, though some deficiencies are likely to be permanent once the facility is in operation. Changes may consist of adjustment or replacement of parts of the technical installations, physical changes or addition in construction, and/or changes in human behaviour.

This research is based on the assumption that knowledge transfer from facilities management to design can reduce the gap between expected performance and actual performance in use. Not only will this lead to better predictions of operation and maintenance budgets, needed staff, environmental impact etc. The operational knowledge is needed for quality assessment throughout the construction projects and will reduce some of the risks associated with investments in new complex facilities like universities, swimming facilities and hospitals. The research points to the need of mobilising facilities management (FM) knowledge to ensure that knowledge and experience from existing buildings is fed into the design and construction of new buildings (Hansen and Damgaard, 2012; Alhaji Mohammed and Hassanain, 2010; Ganisen et al., 2015). Studies have concluded that FM should contribute in different phases of design and construction (Jensen, 2008; Jensen 2012; Due and Stephensen, 2012), and have emphasized the need for the individuals, who will operate the facility, to be involved in the briefing stage (Way and Bordass, 2006). Galamba and Nielsen (2016) focus on the need for building organisational capabilities for sustainable facilities management and point to new ways of collaborating to combine the insights from building design and operation. Chew et al (2017) highlights the importance of integrating “green maintainability” and “green FM” right from the planning and design stage to ensure the actual sustainability of a new facility.

Previous studies assigns FM a quite noble role in the planning and design stage, contributing with knowledge on a variety of issues (Erdener, 2003; Alhaji Mohammed & Hassanain, 2010; Ganisen et al., 2015). This paper investigates the issue from a practitioner’s point of view, offering insight on available practical implementable initiatives to integrate FM knowledge in design, and gives examples on the level of implementation of these initiatives in Denmark. The paper investigates how integration of operational knowledge in building design is currently done in practise in the Danish building industry with particular focus on which initiatives are being used by building clients. This is based on previous research’s identification of the building client as the most important actor to ensure integration of FM knowledge in new building projects (Jensen, 2009). The role of other actors should not be understated, and we recommend future research to investigate the initiatives and possibilities of e.g. designers to ensure FM integration in design.

Faulty design is by researchers identified as one of the main reasons for poor maintainability and lack of operational friendliness (Chew, 2017; Alhaji Mohammed & Hassanain, 2010). The scope of this paper is limited to initiatives in the planning and early design stage. Additional initiatives are important in later stages and in particular, when the facility is handed over to the building client and operation begin, but this is not included in this paper.

Methodology

The overall research paradigm is characterised as pragmatism (Saunders et al., 2009) as it applies a practical approach, integrating different perspectives to help collect and interpret data. The research design is a hermeneutic, multi-method approach consisting of three phases:

1. A review of former research to identify practical initiatives (also named methods or tools) mentioned in the literature for ensuring operational knowledge in building processes.

2. An explorative case study investigating if the recommended initiatives from the literature are used in practice. The case organisation was DTU Campus Service, who owns and operates the university facilities for the Technical University of Denmark. This case study focuses on the collaboration between the internal divisions involved in building projects by asking, if and how the initiatives identified in the previous phase were in use. The case selection was based on a preference of best practices in a Danish context, the choice of an in-house real estate and facilities management organisation with a common strategic context and access to qualitative data about practices of collaboration between design teams and operation and maintenance teams. The study identified additional initiatives, which were not revealed in the literature.

3. A survey of the construction management processes regarding recent swimming facilities in Denmark. The aim was to investigate, if the initiatives from the literature were used in public construction projects and swimming facilities were chosen as they are particular energy consuming and inappropriate design solutions are likely to be costly in the operational phase. The survey asked similar questions as the previous case study and also collected data to be used for benchmarking energy consumption to investigate, if it was possible to document a relation between the use of initiatives in the building projects and the observed building performance once in use. The survey has replies regarding 5 Danish Swimming facilities of 1-10 years of operation.

The case study was conducted in 2013 and the survey was conducted in 2015. More information about the investigated facilities and the data collections is provided in the sections later in the paper, where the findings of each study are presented.

The strength of the methodological approach is the identification of various initiatives that building clients can take to facilitate the integration of operational knowledge in the early design of construction projects. However the explorative character of current practices at the time of study is limited in terms of measuring the actual effect of each initiative.

Theoretical background

The building industry is characterized as a project-based industry and because of that, there is a limited degree of learning from experiences of use and operation of existing buildings. (Lê, 2007; Meng, 2013).

Development of professional FM can be seen as the missing link to bridge the gap between building operation and building design (Jensen, 2009; Meng, 2013).

Over the years, there have been some development and research activities that focus on increasing knowledge transfer from building operation to building design and construction. As early as 1985 The Danish Building Development Council published a recommendation for planning operational friendly buildings (BUR, 1985) and in 2000 the British Building Research Establishment published a report commissioned by the British Institute of Facilities Management (BIFM) about applying facilities expertise in building design (Jaunzens et al., 2001).

The idea of knowledge transfer from building operation to building design is not new. Bröchner (1996) reports experiments from Sweden in the 1960's, but these were less than satisfactory. Bröchner makes a re-evaluation based on expectations that the development in information technology should have made the knowledge transfer easier in the mid 1990's, but concludes that the necessary incentives were lacking. However, Bröchner is concerned with the feedback from building operation of a building to the design team responsible for designing that particular building. In contrast, this paper is concerned with feed-forward from building operation of existing buildings to the design and construction of new buildings.

Recent studies (Kalantari et al., 2017) concludes that in spite of researchers efforts on the topic, there still is a lack of practical recommendations on organization, culture and communication between FM and building project teams. Other studies highlights that IT software and building and design automation will be key elements to close the gap between calculated and actual performance (Corry, 2015; Göcer, 2015; Menezes et al., 2012). Our research focuses on the available ready-to-use initiatives and the implementation of them.

There are many aspects of FM knowledge that ought to be transferred to building projects. In this paper the main focus is on knowledge concerning operation and maintenance. The purpose of transferring knowledge about operation and maintenance to building projects is in general to ensure one gets a new building, that it easy and affordable to operate and maintain, with a good indoor environment, and has a low energy consumption and climate impact.

The research is based on, and a continuation of, former research conducted over the last decade in Denmark by different researchers. Both the case study and the survey presented in the paper are based on a number of concepts or initiatives to support transfer of knowledge from operation of existing buildings to the design and construction of new buildings. From the former research, 31 initiatives were identified as shown in Table 1. The following description will focus on the basis and sources for these initiatives. For broader literature reviews we refer to Jensen (2009 and 2012) and Zuo et al. (2013). This study did not apply one specific model of knowledge transfer as it was an inductive research exploring which initiatives are used for transferring knowledge in practice. The term 'initiative' covers tools, concepts, and tasks that are recommended in literature to be used by the building client in the early stages of design of a new facility.

No.	Initiative	Source
1	Continuous briefing	
2	Detailed building brief	

3	Project review internally/externally	Jensen (2009 and 2012)
4	Public Private Partnership (PPP)	
5	Contractor responsibility for operation and maintenance	
6	Continuous commissioning	
7	Technical Due Diligence	
8	Plan for when and how the right competences should be involved in the project to include operational knowledge in the project	Due and Stephen-sen (2011) and Værdibyg (ValueBuild) (2013)
9	Prepare guidelines and standards for building projects	
10	Use of Life Cycle Cost assessments	
11	Demands of accessibility to building parts (when conducting service, cleaning and replacement, etc.)	
12	Demand of availability of technical assistive technology	
13	Demands about work environment when dealing with methods and materials to cleaning and maintenance	
14	Demand of storage and workshop facilities	
15	Demands of preparation of operational plan and operation budget	
16	Demands of involvement of the operational organisation throughout the building project	
17	Demands of operation and maintenance documentation and instructions	
18	Demands of information and education of the operational organisation and possibly the users	
19	Demand of evaluation of consequences of significant changes during the design phase on operational friendliness, energy efficiency etc.	
20	Demand of evaluation of consequences of significant changes during the construction phase on operational friendliness, energy efficiency etc.	
21	Specific demands to the operational organisations role in starting up the operation	
22	Demands about adaptation and flexibility to changing uses, including possibility to re-disposition and installation changes with least possible constructional intervention	Jensen (2002, 2009 and 2011)
23	Demands of appropriate infrastructure with central location of internal service functions and good internal transport routes	
24	Demand of minimizing the energy and resource consumption (electricity, heating, cooling, water etc.) and environmental impacts	
25	Demand of good indoor climate and work environment with good control possibilities	
26	Demand of maintenance friendliness the building and surrounding areas and good possibilities for servicing technical installations	
27	Demands of dirt absorbing access roads and cleaning friendly surfaces both indoor and outdoor	
28	Demands of durable and easy changeable construction components and materials, including possibilities to reuse building parts	
29	Demands of safety and security of the building, persons and assets	
30	Demands of space and transportation options for waste handling	
31	Demand of reasonable degree of building automation and operational monitoring	

Table 1: Initiatives to support knowledge transfer from building operation to building projects

Initiatives 1-7 in table 1 are based on a typology of knowledge transfer mechanisms from FM to building design and construction. The first part of the typology was initially presented in a journal article (Jensen, 2009). It consists of a two by two matrix with on one side knowledge push from FM – based either on competences (direct involvement) or codification of knowledge - or on the other side knowledge pull from building design – based either on awareness or power. This resulted in initiatives 1-3 and a fourth about regulation, either in terms of requirements from the public or from the building client. An example used in Jensen (2009) is that the Danish state requires public building clients to make Life Cycle Cost assessment. The mechanisms with regulation is left out of Table 1, because use of life cycle cost assessments are included as initiative 10. The typology was further developed in another journal article (Jensen, 2012). The initial typology was supplemented by another two by two matrix with on one side knowledge pull from FM in terms of validation of performance – based either on integration (direct involvement) or outsourcing - or on the other side knowledge pull from building construction – based either on control or responsibility. The mechanisms with knowledge push from FM in terms of setting requirements for design was termed front end knowledge transfer and the mechanisms with knowledge pull from FM in terms of validation of requirements was termed back end knowledge transfer.

Initiatives 8-22 were developed during a best practice project conducted alongside an action research project concerning the planning of a new university building. The best practice project was based on a row of workshops involving a group of 18 FM practitioners and two facilitators. This project resulted in a Best Practice Guide in Danish (Due and Stephensen, 2012), which was further developed and published as one of many guidelines from the Danish cooperative organisation ValueBuild – initially in Danish (Værdibyg, 2013), but the guideline is in the process of being translated to English (see http://www.vaerdibyg.dk). It appears here in the author's own translation.

Initiatives 22-31 are from Jensen (2002, 2009 and 2011) which refer a study of research, development and literature concerning FM and briefing for building projects.

The accumulating 31 initiatives support the two different types of knowledge; explicit and tacit, or both. They support knowledge push as well as knowledge pull, and knowledge transfer from front end as well as from back end. The following section will show the results of investigating the use of the initiative in the case study and the survey.

The case study of DTU Campus Service

Introducing the case

The Technical University of Denmark (DTU) is located on several sites, including the main campus 12 km north of Copenhagen in Lyngby. Lyngby Campus is intensively increasing in the years 2010-2020 holding a construction budget of more than DKK 5 billion (roughly Euro 700,000). A technical university is characterized as being a so-called "wet" university with many laboratories and other highly specialised and complex technical systems. This means that the facilities are relatively expensive and complicated both to build and to operate. DTU Campus Service is the FM department of the university, including an Operation division and a Building client division, employing in total 215 people (2015). DTU Campus Service thereby has a considerable internal knowledge of building operation and a strategy for operational friendly and sustainable buildings.

Interviews and document analysis

The study included three face-to-face interviews, two of them were individual interviews and one was a small focus group interview with two interviewees. The face-to-face interviews were supplemented with two interviews by mail. Furthermore, building briefs of two recent building projects were analysed.

Interviews with the Building Client division and the Operation division maps the degree of implementation of the 31 initiatives presented in theory section. Analysis of building briefs allows a systematic examination of which of the 31 initiatives are included in the building project already in early design phases. The result is a state-of-the-art of which initiatives DTU Campus Service have implemented in early design phases to ensure integration of knowledge from operation to new building projects.

As mentioned, two of the interviews, one in each of the two divisions, were conducted with cardboards cards as an artefact, each with one of the 31 initiatives written on it, see Figure 1. The interviewer handed the interviewees the cards one at a time, allowing time to talk about the use of the initiative. The interviewees were asked to place the cardboard cards one at the time under the headlines: “Implemented” or “not implemented”. During the first interview, two other headlines were added: “Limited implemented” and “Planned to be implemented soon” on the proposal of the interviewee. In the Building Client division, two experienced project managers were interviewed with cardboard cards in a small focus group interview. Operation division is subdivided into smaller sections, and the manager of one of these sections were interviewed with cardboard cards. Furthermore, the head of the Operation division were interviewed. Table 1 was presented to additionally two employees of Operation division for validation. The validation was done by mail.

Figure 1. Examples of cardboard cards with the 31 initiatives used during interviews

Findings of the case study of Campus Service.

The case study shows that a large number of the 31 initiatives were implemented in DTU Campus Service. Furthermore, initiatives not found in the literature review were also used, and initiatives not described by literature occurred during the interviews, when obstacles and the importance of cooperation were discussed with the interviewees. Table 2 shows the additional 11 initiatives identified with the interviewees during the cardboard card interviews.

No.	Initiative	Source
32	Clear statement that operational friendly buildings are a high priority	Campus Service, DTU
33	One-point access in Operation Division (A *bridger*; person between building client division and operation client division)	
34	Establish a professional building client/construction management division	
35	Operations represented in management group	
36	FM considered a strategic discipline	
37	Care for good relations between Building Client Division and Operation Division	
38	Demands on Life cycle cost analysis of the project as built	
39	Log deviations from the guidelines and standards for building projects (see initiative 9, table 1)	
40	Agreements on how and what is included in internally reviews conducted by the operational staff	
41	Establish a safety net to secure considerations of comments, demands and ideas mentioned in wrong phases	
42	Care for good relations between design team, construction team and Operations Division	

Table 2: Additional initiatives by DTU Campus Service

Eighteen of the now 42 (31 + 11) initiatives were categorized as well implemented in DTU Campus Service. Well-implemented initiatives assumable have a positive effect on the performance of the new facility. These 18 initiatives are included in most building project in DTU Campus Service, and the interviewees describe these initiatives as “good initiatives”. Examples are detailed building brief (2), demands on good indoor climate and work environment (25) and demands on energy efficiency (24). The other well-implemented initiatives were 1, 8, 11, 12, 13, 14, 16, 22, 23, 29, 31, 34, 35, 36 and 37.

Fourteen of the 42 initiatives were categorized as only limited implemented, and are only used in some of the building projects in Campus Service. The interviewees describe obstacles and frustration with these initiatives and they appear to be unnecessarily resource intensive in their current level of implementation. Examples of limited implemented initiatives are written guidelines and standards for new facilities (9), internal project review (3), demands of operation and maintenance material (17) and Life Cycle Cost assessments (10). Other limited implemented initiatives were 15, 18, 26, 27, 28, 32, 33, 38, 40 and 42.

Five initiatives (6, 7, 21, 39 and 41) were, according to the interviewees, planned to be implemented soon, including building commissioning. The other five initiatives (4, 5, 19, 20 and 30) were either not known or for various reasons not implemented, including contractor responsibility for operation and maintenance (5).

The survey of five swimming facilities

The questionnaire survey covered five public swimming facilities from five different municipalities in Denmark. Swimming facilities have a high degree of technical complexity, particularly in terms of water treatment with purification systems that need to be operated competently and carefully to prevent health problems among the guests. Because of that, one needs to pass a special course to be responsible for operating swimming facilities In Denmark. The respondents were all responsible for operation of the swimming facilities. The criteria for selecting the facilities included that they were constructed or refurbished within the last 10 years to make it likely that information from the building project was in the memory of the respondents.

The questionnaire focussed on two issues. Firstly, what initiatives to transfer operational knowledge into construction had been used and with how good an effect according to the perception of the respondents. Secondly, what was the energy consumption in terms of electricity, water and heating. Besides, the questionnaire included basic data about the swimming facilities like number of m^2 and guests to allow calculation of key indicators for benchmarking. The results of the second part is not included in this paper as it did not lead to any clear conclusions.

The main results for the first issue are shown in Figure 2. For each of the 31 initiatives presented in the theory section it includes information for how many of the swimming facilities the initiative was used with good effect, with limited effect, not used, or use not known by the respondents. All initiatives were used in at least two of the five facilities. Initiative 11 concerning “Demands for accessibility to building parts” was used the most with good effect - in three facilities. Five other initiatives (15, 17, 23, 29 and 30) were used with good effect in two facilities. Eleven initiatives were used only with limited effect or not used. Used with limited effect was the largest category with 84 answers, used with good effect was the smallest with 27 answers, not used or not known together had 44 answers.

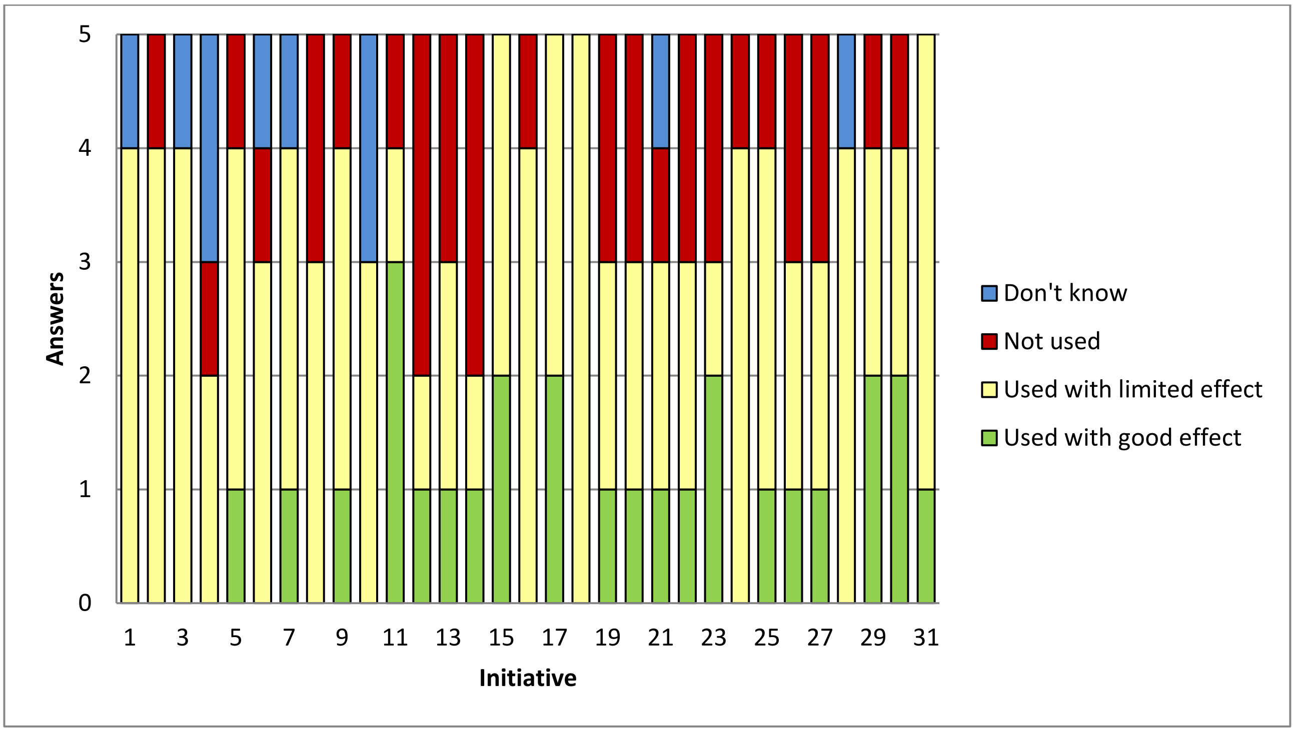

Figure 2. Initiatives used in five swimming facilities (graphical overview of answers)

Analysis

Who should care?

The literature review identified 31 initiatives. The case study of Campus Service added 11 initiatives, thus 42 initiatives in total. The main responsible to take care of the use and thereby ensuring the benefits of the initiatives is the building client or owner. Besides private housing, a building client is rarely a single person but an organisation of some kind and this blurs the otherwise clear statement of responsibility. The building client in both the swimming facilities and Campus Service consist of three main parties involved in the building projects, illustrated by Figure 4.

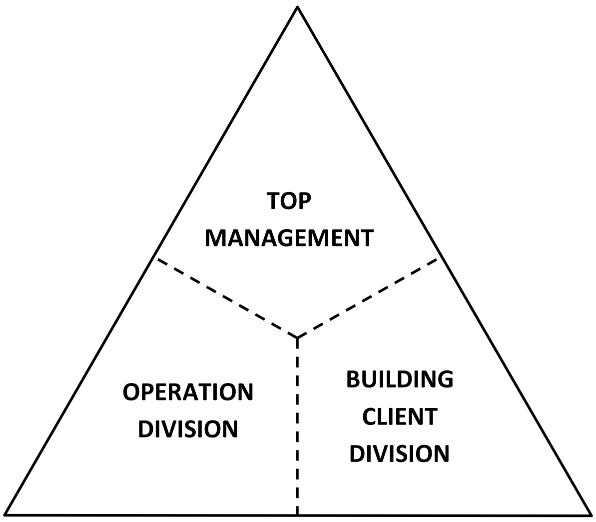

Figure 4: The building client seen as three-partite.

1. Top Management: Managing the building portfolio, orders new facilities. Head of both building client division and operation division.
2. Building Client division: Manage the building projects on behalf of the top management.
3. Operation division: Operates and maintain existing and possibly future facilities. In the swimming facilities, operation is decentralized and located at the specific swimming facilities, while the building client and Top Management are placed centrally at the municipally. In DTU Campus Service, the Operation division is located close to Building Client division and Top Management.

The three-partite building client is recognised in a large number of public and private building projects. In cases, where one party is missing, for instance if the future operation division is not established yet, the two other parties must take care of the initiatives of the missing party, possibly by external competences like consultants.

The three parties should not be confused with the three often used terms for FM management levels; strategical, tactical and operational. As an example, the list of initiatives, which the operational division should care for, includes both initiatives on tactical and operational level.

In DTU Campus Service, and possibly in similar organisations, it is a common assumption, that the Building Client division is responsible for including operational knowledge in the building projects, since they are managing the projects. Our analysis suggests that it can be helpful to revise this assumption and acknowledge the important roles of each part in order to realize the sustainable potential of new facilities.

The 18 well-implemented initiatives in DTU Campus Service only included one of the initiatives the Operation division should take care of. It included 13 initiatives taken care of by the Building Client division and four initiatives taken care of by the Top Management. This indicates that the operational division struggles the most with implementing initiatives in DTU Campus Service. A similar picture was not found in the survey of the five swimming facilities. It was not a part of the research project to investigate reasons for the lack of well implemented initiatives in the operational division of Campus Service, but possible reasons could be lack of demand from management, overshadowing focus on operational day-to-day tasks, lack of competences, lack of resources, lack of incentives, or cultural reasons. We recommend future research to investigate this further.

Four degrees of implementation

The results of the case study and the survey shows that the majority of the initiatives are in use. However, some of the initiatives are only limited implemented or used with limited effect. This indicates that the initiatives in themselves are not sufficient, but they need to be adapted to a specific context or supported by other deliberate actions to achieve the best effects. Figure 5 illustrates that initiatives not used, not surprisingly, has no effect on the sustainability of the new facility, limited implemented initiatives has no or minor effect, whilst the well-implemented initiatives can have a high effect on realizing the sustainability potentials of the new facility. In the case study of DTU Campus Service well implemented initiatives constituted the largest category; while limited implemented initiatives made up the largest category in the survey of the swimming facility.

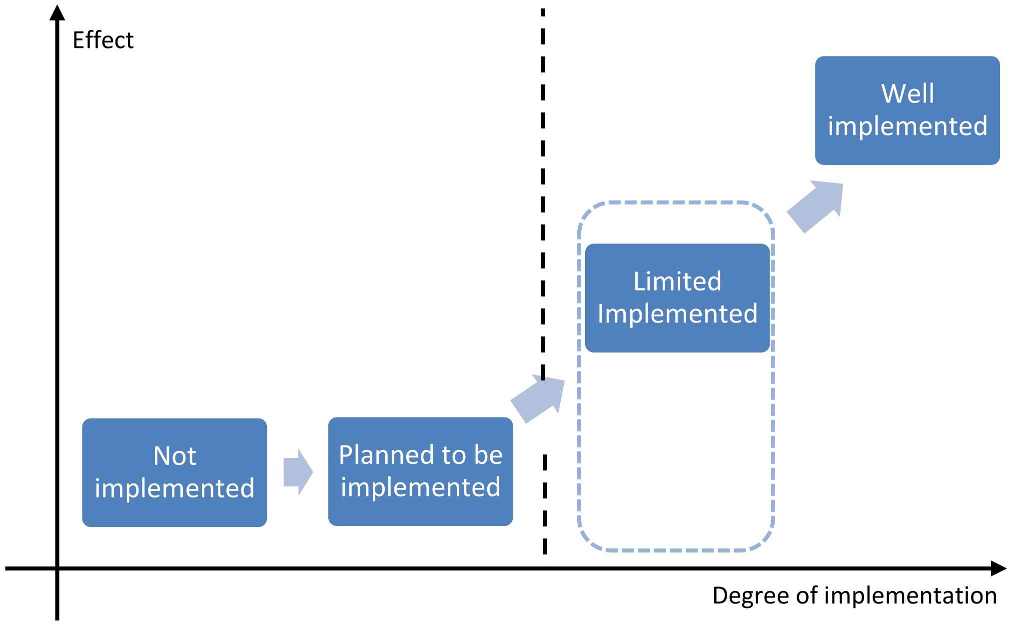

Figure 5: Impact on realizing the sustainable potential of the new building.

Proposal for a revised list of initiatives

Table 3 presents a proposal for a revised list of the originally 31 + 11 initiatives to be considered in early design phases to contribute to realizing the sustainability potentials of a new facility. The initiatives are listed by whom of the three-partite building client should take care of the initiative, all though most initiatives requires contributions from more than one party. Initiatives on the original list that are regarded as very similar and overlapping have been reduced, initiatives describing demands to be included in the building brief have been gathered to one list of demands and two of the 11 additional initiatives from DTU Campus Service have been excluded as they were described as not very good.

	<u>Top Management should consider:</u>
32	Clear statement that operational friendly and energy efficient buildings are a high priority
34	Establish a professional building client/construction management division
35	Operation Division represented in management group
36	FM considered a strategic discipline
37	Care for good relations between Building Client Division and Operation Division
	<u>Building Client Division should consider:</u>
1	Continuous Briefing
2	Detailed Building Brief
3A	Project review externally
4	Public Private Partnership (PPP)
5	Contractor responsibility for operation and maintenance
7	Technical Due Diligence
10	Use of Life Cycle Cost assessments

A	List of demands to include in the building brief (initiatives 11, 12, 13, 14, 15, 16, 17, 18, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31 from table 1)
39	Log deviations from the guidelines and standards for building projects (see initiative 9)
41	Establish a safety net to secure considerations of comments and demands mentioned in wrong phases
42	Care for good relations between design team, construction team and Operations Division.
19	Demand of evaluation of consequences of significant changes during the design phase on operational friendliness, energy efficiency etc.
20	Demand of evaluation of consequences of significant changes during the construction phase on operational friendliness, energy efficiency etc.
	Operation Division should care for:
9	Prepare guidelines and standards for building projects
B	Specifications of demands to include in the building brief
17	Specifications on demands of operation- and maintenance material from contractors (and preparations to receive documentation according to hand-over time schedule)
15	Specifications of demands of operational plan and operation budget
40	Agreements on how and what is included in internally reviews conducted by the operational staff
3B	Project review internally
6	Continuously commissioning
8	Plan for when and how the right competences should be involved in the project to include operational knowledge in the project.
21	Specific demands to the operational organizations role in starting up the operation

Table 3: Initiatives organized by responsibility

Discussion

A more comprehensive and broader literature review could have resulted in more and different initiatives than the 31 initiatives considered in this study. One of the initiatives that has not been included in the study is the British concept called “Soft landings” (BSRIA, 2014). Soft landings principles are designed for building clients and their professional teams as guidance to bridge the gaps between the different stages of a building project, in particular from construction to operation and from operation to design.

Soft landings does not replace existing tools and concepts, but can be seen as a framework for the entire process. It is currently not a common practice in Denmark, but Soft landings could possibly serve to gather the fragmented use of initiatives already implemented by Danish building clients investigated in this paper. As examples, initiatives on detailed building brief, project reviews, commissioning, plan for involvement of FM personnel, demands on training of FM and users, and demands on energy consumption (initiatives 2, 3, 6, 8, 18, 24 in table 1) are included in the Soft landing concept (BSRIA, 2014). In our current research, we are investigating the relevance of a comprehensive framework like Soft landings.

The initiatives described in this paper include both large concepts and more simple tools. It makes it difficult to compare the use of the initiatives, as the use of one initiative, e.g. commissioning, could have same effect as the use of several simple initiatives or even cover several simple initiatives.

The case study of DTU Campus Service added 11 initiatives not found in the literature review. Despite the limitations of the literature review, it indicates the need for more initiatives than currently provided in Danish guides and handbooks on the topic. Campus Service has developed well-implemented initiatives that could serve as inspiration for other building clients, including the swimming facilities. The survey methodology of the swimming facilities did not aim at finding additional initiatives, but possibly that could have resulted in other or similar additional initiatives. Studies of other building clients could possibly add even more initiatives.

Conclusion

Based on former research we initially identified 31 initiatives, which are expected to improve the integration of operational knowledge in building projects with the purpose of realizing the sustainability potential of new facilities and bridging the performance gap. These 31 initiatives formed the basis for both the case study of a university campus and the survey of five swimming facilities presented in this paper.

The case study and the survey showed that many of the initiatives are used. DTU Campus Service uses more initiatives than the building clients of the swimming facilities, and uses initiatives not found in literature. However, using the initiatives does not necessarily contribute to better performance of new built facilities. The paper differs between well-implemented and limited implemented initiatives. It takes deliberate effort to get the initiatives well-implemented and fully adopted in the organisation to achieve a good effect.

The building client in DTU Campus Service and the swimming facilities includes three main actors responsible for the use of the initiatives; Top Management, Building Client division and Operation division. The paper suggests that each party is responsible for a share of the initiatives, though cooperation between the three parties is a necessity. The absence of one party requires further actions from the parties present. A revised list of available initiatives based on the findings in the studies distributes the initiatives on the main actors, and serves as an overview of appropriate initiatives to realize sustainability potentials of new facilities by the different parties involved in building projects and building operation.

This study has been inductive and exploratory based on a limited review of existing literature. We have for instance not included literature on knowledge communication. In our further research, we will conduct a deeper and more systematic literature review to gain a deeper insight into knowledge management as a basis for a comprehensive empirical study of knowledge transfer.

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Appendix 2

Paper B

DTU Library

Knowledge transfer between building operation and building projects

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Knowledge Transfer between Building Operation and Building Projects

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Abstract

Purpose – This paper aims to investigate how knowledge concerning operation and maintenance of buildings can be stored and transferred between the parties responsible for building operation and new building projects.

Design/methodology/approach – The paper is theoretically based on knowledge management with a particular focus on interdepartmental knowledge transfer between departments responsible for operation and maintenance and departments responsible for building projects in organisations with large and fast changing building portfolios. The paper includes a case study of the facilities management organisation of the Technical University of Denmark with data collection mainly by interviews with managers and staff in the relevant departments in this organisation.

Findings – The case organisation seems to be aware of the importance of sharing and transferring their organisational knowledge. Over the past five years, the organisation has developed different tools and adopted several processes, aiming at integration of the knowledge they possess from many years of operation and maintenance of the existing buildings. However, there are many situations, where the tools and processes do not work efficiently, and therefore the knowledge transfer is not sufficiently effective. It is apparent that the best results can be achieved only if the different actors involved in a construction project collaborate aiming towards the same objectives.

Originality/value – The paper presents and evaluates a case of interdepartmental knowledge transfer in an organisation, which has a strong focus on improving the interconnections between building operations and planning new building projects.

Keywords: Project management, Knowledge transfer, Building project, University campus, Building operation, Building client

Paper type: Research paper

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1 INTRODUCTION

This paper concerns a challenging topic within the construction industry and the Knowledge Management (KM) discipline. The issue that is examined is knowledge transfer (KT) between building operation and project management of construction projects to ensure appropriate performance of new facilities.

According to literature, the involvement of Facilities Management (FM) expertise in a construction project from its early phases is of great importance (Jaunzens et al, 2001; Jensen, 2009; Hansen et al., 2010; Meng, 2013). Although it might be assumed that knowledge transfer could be approached in the same way as it is in other kind of industries, the nature of the construction industry makes it difficult. Construction firms move from one building project to another, which usually differs substantially from the previous one. The lack of distinct similarities between these building projects makes the project management team more reluctant to consider, extract and reuse knowledge that has been acquired during past projects (Lê, 2007).

The purpose of the paper is to answer the following research question: how knowledge concerning operation and maintenance (O&M) of buildings can be stored and transferred between the parties responsible for building operation and new building projects? Besides, the paper aims to clarify the KT tools and processes that have been developed and are being used within the case organisation.

The paper is based on a case study of the FM organisation of the Technical University of Denmark (DTU) called DTU Campus Service (CAS). They are in charge of management, operation and development of all the existing facilities of the university as well as a huge construction program of new buildings at its main campus, following a number of mergers with former independent institutions. The case study examines the knowledge transfer between the building O&M department and the department responsible for new buildings projects – the Real Estate Project Management Office (PMO). The methodology of the study is described in section 2 followed by a literature review on KM, focussing on theory on Knowledge Transfer (KT) related to the construction industry in section 3. The case study is presented in section 4 followed by discussion in section 5 and conclusion in section 6.

2 METHODOLOGY

CAS was chosen for the case study, because they currently are one of the largest building clients in Denmark, they have a large in-house departments responsible for O&M of buildings, and earlier research (Rasmussen et al., 2014) has shown that CAS is deliberately aiming at increasing knowledge transfer between building operation and building projects. The methodological approach used during the research was divided into three stages.

In the first stage a broad literature review was conducted. The field of KM was examined, giving weight to aspects regarding KT in the construction industry and particularly in KT between FM and building design. This was supplemented by two interviews with external experts.

The second stage focused on qualitative data collection, using semi-structured interviews, which took place during spring 2015. Eight interviews were conducted with people from CAS. Further information about the interviewees are given in section 4. The interviews were supplemented with a study of documents from CAS.

The third stage included analysis and categorization of the data that were gathered through the interviews and document studies. The categories in which the data were placed were regarding the KT behaviour and activities that CAS uses.

3 LITERATURE REVIEW

KM is a relatively new management field (Alvesson and Kärreman, 2001), established on the argument that it is a challenging task, though an attractive objective, for an organisation to fully utilize the knowledge that they create or possess. The information technology revolution is one of the crucial reasons, why increased access to knowledge has become possible. KM can be described as the strategy that aims at development of organisational knowledge through accumulation of data and information, along with past experience derived from the human resources (Dubey and Kalwale, 2010).

A common way to distinguish knowledge is into two fundamentally different categories; explicit and tacit (Heisig, 2009; McBeath and Ball, 2012). The explicit knowledge of an organisation is systematic and can easily be codified and communicated. Once codified explicit knowledge can be distributed within the organisation and reused. Examples of explicit knowledge are templates, patents, reports and checklists. Tacit knowledge is non-articulated knowledge and thus inherently personal, which makes it difficult to be extracted out of human minds, formalized and disclosed in manuals in order to be shared or transferred. Tacit knowledge includes individual experience along with personal belief, perspective and values (Pan and Scarbrough, 1999; Vianello and Ahmed, 2012). This feature constitutes an obstacle to the transferability of tacit knowledge (Lundvall, 2004).

Knowledge codification is an important part of the knowledge refinement process, which includes the techniques that extract, filter, clean and reform knowledge in order to enter the various knowledge repositories. Such repositories hold both organisational knowledge and information, either in an electronic form (i.e. knowledge databases), or in a documented form (Davenport et al., 1998).

Technology has a crucial role in the acquirement and codification of organisational knowledge as it can store large amounts of knowledge, allowing its smooth distribution and re-use. Therefore, a robust Information and Communication Technology (ICT) infrastructure to support both the codification and storage of the organisational knowledge is essential. The selection of appropriate technology should be aligned with different organisational aspects. The most important aspect is organisational culture as it is the one that affects internal communication and KT, with operational, technical and cost aspects being significant as well (Smith, 2001).

Technology does not transfer knowledge on its own, but relies on the people using it. However, Alvesson and Kärremann (2001) point at IT-based tools for KM as important symbol, communicating to the people in the firm, that in this firm, knowledge is shared. Thus, ICT-based tools contribute to establish a knowledge sharing culture, and is in that regard self-perpetuating. Ahmed-Kristensen and Vianello (2015) states: “The success of the knowledge management strategy is not in the amount of information that is stored into the repositories but in how the information is reused in order to achieve a predefined aim (…)”

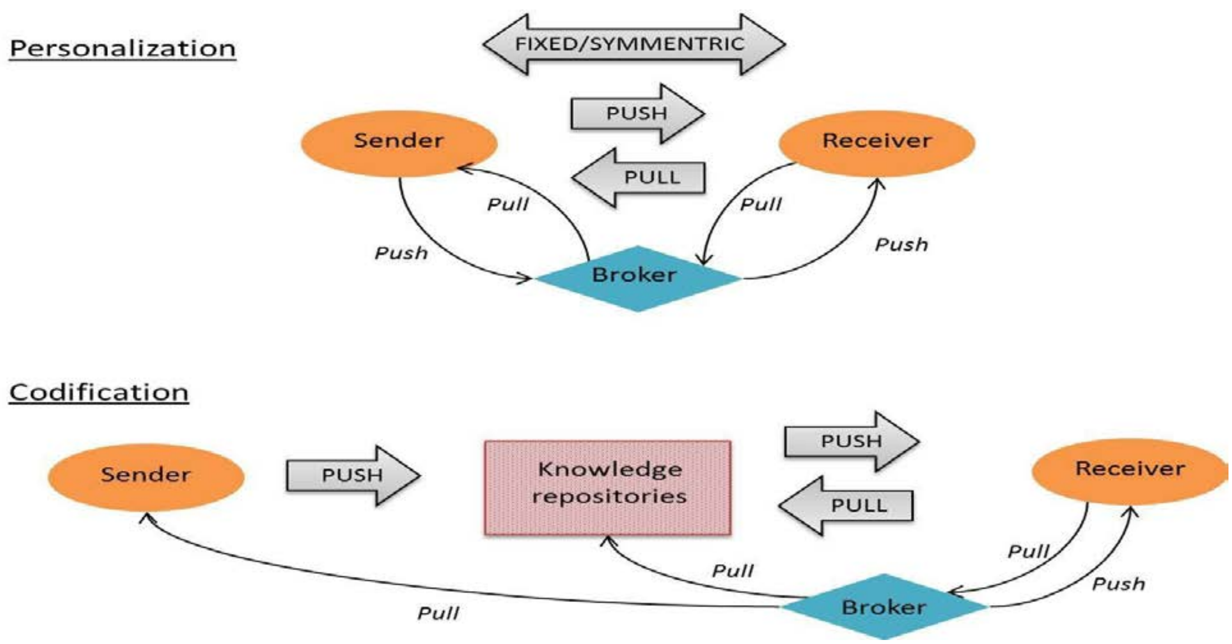
The success of KT is heavily based on the existence of cooperative behaviour between the participants. Appel-Meulenbroek (2014) distinguished cooperative behaviour into two main types;

1) interaction and 2) collaboration. Interaction adds structure to how departments interrelate and describes a more formal kind of cooperation with routine activities, such as scheduled meetings and teleconferences, routine calls or standardized documentation. Collaboration represents the unstructured, affective nature of intradepartmental relationships portrayed by more informal processes and mutual understanding between the different parties, which work together sharing a common vision and the same objective. See table 1.

Table 1. Organizational cooperation, activities and communication channels (Kahn, cited in Appel-Meulenbroek, 2014)

	Suggested activities	**Means of communication**
Interaction	Meetings	Meetings, committees/task forces, phone conversations, phone mail, electronic mail
	Documented information exchange	Forms, memorandums, reports, fax
Collaboration	Activities to achieve goals collectively, mutual understanding, informally work together, share idea's information and/or resources, share the same vision for the firm and work together as a team.	

Figure 1. KT through personalization and codification strategies (Vianello, 2011)



KT mechanisms are currently a hot topic in the KM field (Zuo et al., 2013). The initiation mechanisms of KT can be categorized into push, pull and fixed (or symmetric) mechanisms. Knowledge push represents an initiation mechanism, where the sender provides knowledge without any particular demand for it. Knowledge pull is a mechanism, where the receiver is the one that requests the knowledge, while a fixed KT initiation mechanism depicts the scheduled KT activities, such as regular meetings, where both sender and receiver play an active role through established interaction activities (Ahmed-Kristensen and Vianello, 2015).

Another type of categorization of the KT mechanisms is the distinction between personalization and codification strategies (Lê, 2007; Vianello and Ahmed, 2009; Vianello, 2011; Jensen, 2012; Ahmed-Kristensen and Vianello, 2015). The personalization strategies represent a more informal communication between the participants and can be related to the collaboration activities. Through these strategies, new knowledge is generated and existing tacit knowledge becomes available to the receiver. On the other hand, the codification strategies refer to the transfer of the explicit knowledge that is captured into knowledge repositories, for instance ICT-based tools as databases, related more to the interaction activities.

The distinction between between personalization and codification strategies are illustrated in Figure 1 (Vianello, 2011). It shows the three mentioned initiation mechanisms – push, pull and fixed/symmetric – are placed directly between sender and receiver in the knowledge transfer with a personalization strategy, whereas the knowledge transfer in the codification strategy is mediated via knowledge repositories and the fixed/symmetric initation mechanism is not included. In both strategies, a knowledge broker is included as an alternative or supplement to the other transfer channels. The knowledge broker can be an internal mediator or an external consultant.

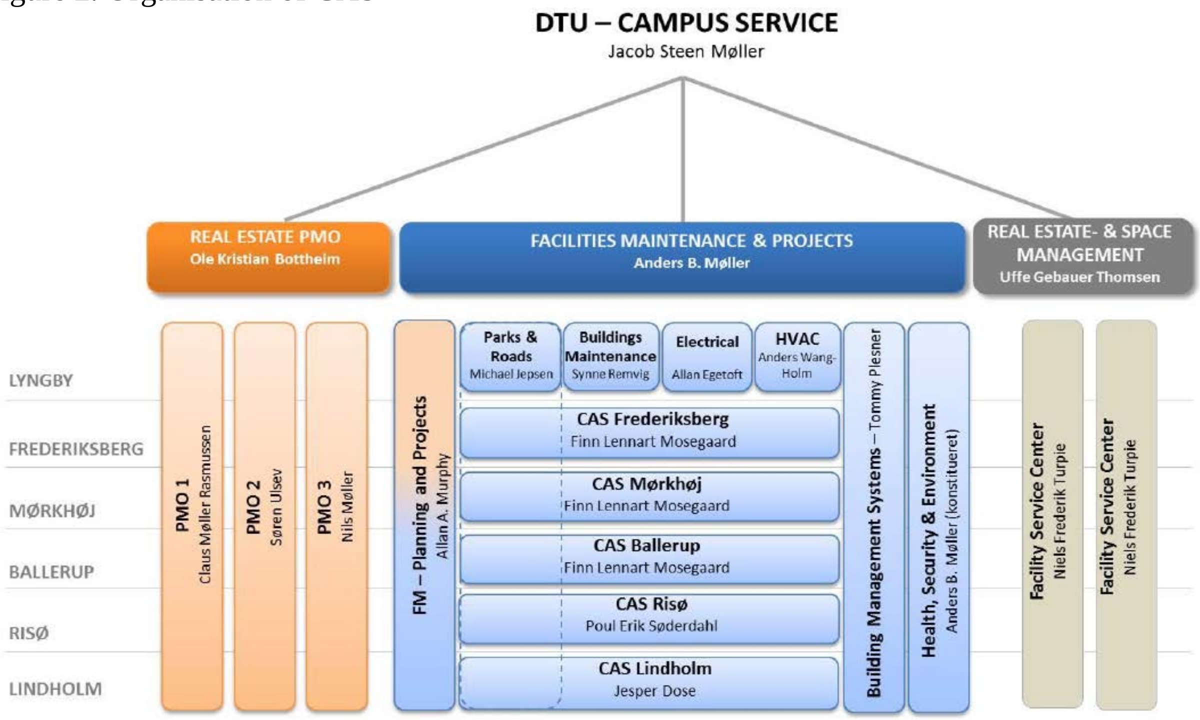
4 CASE STUDY

The main purpose of DTU CAS is to ensure that all students and personnel are provided with the best possible physical working conditions in all DTU’s 17 different locations around Denmark and Greenland. CAS is headed by a campus director with reference to the university director and is subdivided into three different departments, each headed by a director, see Figure 2.

These departments represent the core activity areas of the organisation; Real Estate PMO, Facilities Maintenance and Projects (O&M), and Real Estate and Space Management. The organisation is physically distributed on six locations, employs approximately 180 employees and has its headquarters at the main campus in Lyngby, north of Copenhagen. The case study concerns the main campus, owned by DTU, as it is currently expanding in order to support the centralisation of the external research institutions, currently placed in rented buildings elsewhere, as well as the future demands deriving from the increase of students and staff.

The eight interviewees from CAS included the heads of the three departments as well as section leaders and project managers from the O&M and PMO departments, whose interaction was examined.

Figure 2. Organisation of CAS



4.1 KM in CAS generally

According to the literature review *interaction* as a cooperative behaviour for KT is more structured and formal than *collaboration*. Interaction in CAS is established on a phase-gate model that has been developed based on the principles of PRINCE2 project management model in order to support every new construction project. A building project in CAS is divided into four main stages; Conceive, Design, Implement, and Operate (CDIO). Each of these stages is subdivided into different phases, representing the activities that take place during the project execution. All CAS departments are involved in a building project, along with external resources, depending on the phase that the project is in. Each phase is followed by a gate-point, where activities that support the interaction of the involved in the project parties occur. These activities are usually scheduled meetings or exchange of documented information for review or approval from CAS units or other project participants.

Collaboration as a type of cooperative behaviour for KT includes unstructured and informal organisational processes. Although CAS has a structured cooperative behaviour in terms of *interaction*, when it comes to *collaboration*, they have not yet achieved an adequate level within the whole organisation. A clear common goal regarding KT or KM has not been defined. Employees in CAS know that they have to share knowledge between them and transfer knowledge to another department when necessary, but a strategy has not been formally stated to clarify, why and how it should be done. The heads of CAS departments collaborate to a higher degree than their employees do, and during the interviews, a ‘close relationship’ is mentioned. At the time of study the three departments were placed in three different buildings at the campus, which may result in the development of subcultures within the organisation. Even though subcultures can be considered as a positive consequence, because employees feel as a part of a community and therefore may collaborate and perform better, it can prevent the development of a common organisational culture. However, a new building was being constructed in order to gather CAS departments, aiming also to develop a strong universal organisational culture.

According to the literature referred to in section 3, KM depends heavily on ICT-based tools. Since CAS is moving to a direction, where the knowledge arising from previous projects is intended to be shared in order to be reused, they invest in ICT systems to assure competent and efficient knowledge sharing throughout the organisation. Two such systems are the Building Information Modelling (BIM) for 3D models of both existing and new buildings and a Computer-Aided FM (CAFM) system, which will be used among other things for maintenance management. However, both systems are not fully developed and updated with data of all buildings and projects yet. CAS has furthermore implemented a project-web tool to manage documents and drawings in the building projects. CAS thereby has ICT-based tools to handle knowledge derived from the different lifecycle phases of the buildings.

4.2 KT from O&M to PMO

The main activities in O&M are the amendment of the faults that are reported through a helpdesk system, and the management of planned maintenance projects. However, its responsibilities also include transfer of knowledge created during building operation and maintenance to PMO to assist reuse of this knowledge by the project managers during their projects.

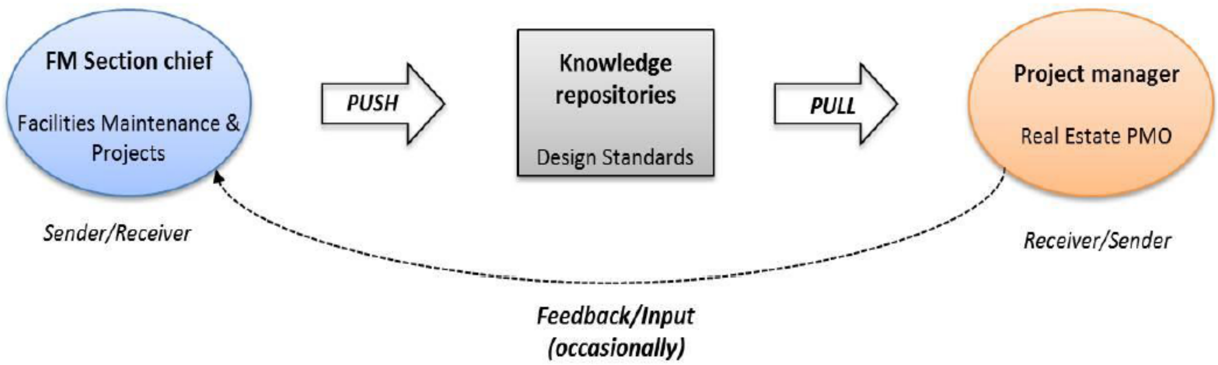
The type of KT from O&M to PMO can be described both as knowledge push and as knowledge pull depending on the phase of the project. During the first meetings in the design brief phase of a project, according to the project model, O&M section leaders 'push' knowledge, through the design specifications that they pass on to the project team. In this way, O&M sets the requirements that assure the efficient future maintenance and alignment with existing buildings on campus. On the other hand, PMO project managers call meetings with O&M section leaders and try to involve them in every project phase, in order to 'pull' knowledge useful for the project. In these meetings, the O&M section leaders are asked to give feedback on the building projects based on for instance floor plans or 3D models.

A critical issue that has an impact on several KT activities of O&M is, according to the interviewees, lack of human resources. The main responsibility of the O&M section leaders is to coordinate basic operation and maintenance activities and define the new maintenance projects they are in charge of, with respect to the future needs of the buildings. Additionally, after each phase of a PMO project, they have as an extra duty to participate in meetings with the project managers and provide the project team with feedback by commenting on project drawings and documents. These tasks are time-consuming processes and sometimes O&M section leaders cannot attend the meetings or give feedback on the projects on time. In order to improve the efficiency of the O&M sections and support the O&M section leaders, CAS employed extra personnel over the last years.

A rather new method that O&M has started to use extensively in the recent past, in order to assist the KT from their department, is codification of their departmental knowledge. This codification is based on production of documents that standardize specifications or solutions and are applicable in both new construction and refurbishment projects. The main standardization method used by CAS is the development of design standards. The development of these standards started on the request of a PMO project manager, who wanted to simplify the facilitation of KT from O&M. They define the design requirements that have been set by O&M, having as main parameters design consistency, level of complexity and cost of maintenance. For instance, a toilet room standard aims to prevent designing different toilet rooms around the campus while saving time during design. The reasoning behind is that it is more efficient to maintain, for instance keep spare parts for, one type of sanitation on Campus. Design standards are generic demands and supplements the abovementioned project specific requirements in the brief for the projects. Thus, design standards are repositories for the information that heads of O&M previously repeated orally in the brief phase of each building project.

The design standards are distributed to the project team by the O&M section leaders in the design brief phase of each project; thus, the KT through the design standards can be described as knowledge push as shown in Figure 3.

Figure 3. KT from O&M to PMO through design standards



From this moment the responsibility regarding their implementation on the design of the project passes to the project managers. However, it was found in the interviews, that O&M section leaders often discover that the decisions that have been made during the project phases are not compatible with the standards' requirements. This can happen either because the requirements set in the standards could not be applied to the specific project or because the project team disagrees with them.

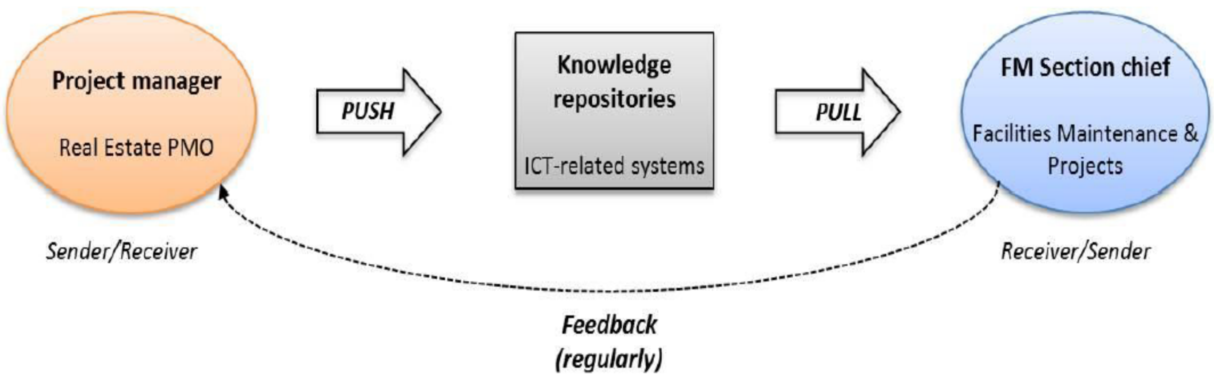
4.3 KT from PMO to O&M

PMO is in charge of all the new building projects of DTU. The project managers in PMO comprehend fully that after the completion of a project, O&M personnel will inherit and be responsible for the operation and maintenance of the building; therefore the O&M personnel needs to be familiar with the building and know how its technical systems function. The head of PMO uses what he calls the "gift metaphor", where the new building is seen as a gift that PMO is wrapping up in order to give it to O&M. When the people in the latter department unwraps the gift, they should be able to use it; hence PMO should provide them with all the necessary knowledge and instructions. To achieve this, PMO uses processes which facilitate transfer of the knowledge that is created during the different project phases. The knowledge that arises from PMO and could be beneficial for O&M is mainly associated with new processes, technologies or materials that can substitute the currently used. Usually, project managers try to push this knowledge to the O&M section leaders, during their meetings after each project phase.

However, according to the interviewed O&M section leaders, KT from the PMO project managers is not an often occurring phenomenon. Moreover, the knowledge that is transferred is not always considered relevant or useful for the O&M section leaders because these two participants "look at the project with different eyes". The O&M section leaders are more concerned about buildings which maintenance does not require too much effort and expenses, while the project managers are focused on several goals for the project, for instance functionality and aesthetics. This can possibly, but not necessarily, conflict with the O&M focus.

The amount of time that O&M usually devotes to KT activities is limited due to their lack of human resources. Hence, KT from PMO to O&M can be described as knowledge push, supported by the use of ICT-based systems. Project managers push the information and knowledge that arise during a project into the ICT-based systems that serve as knowledge repositories – including a project-web called iBinder. Following, it depends on the availability of the O&M section leaders to pull and use this knowledge, as shown in Figure 4. The same knowledge push from the project managers is happening also during their meetings with O&M section leaders after each project phase. There, the project managers are 'pushing' information and knowledge regarding the project to the FM section leaders, requesting their comments.

Figure 4. KT from PMO to O&M



On the other hand, project managers in PMO are also engaged with tasks related to their projects, thus sometimes their work overload does not allow them to hold discussions and give feedback to the comments that they receive from both O&M section leaders and user groups. Therefore, some of the decisions are not made in common and this can cause tensions or disappointment between the participants.

4.4 Push and pull

As described above, the two departments transfer knowledge between them using both push and pull. Table 2 lists the main mechanisms identified in the previous section. It is noticeable, that in contradiction to PMO, O&M do not use pull as a mechanism to transfer knowledge. Even though knowledge transfer often take place at phasegate meetings, these are not regarded a fixed or symmetric mechanisms, because the meetings are called for by PMO concerning their project documents and information.

Table 2. Knowledge transfer mechanisms in CAS

Mechanism	Direction	Examples
Push	O&M ⟹ PMO	• Design standards (generic)
	PMO ⟹ O&M	• Phasegate meetings: Information about the project is given to O&M • Documents and drawings put in ICT-based tool
Pull	O&M ⟸ PMO	
	PMO ⟸ O&M	• Phasegate meetings: Feedback from O&M

5 DISCUSSION

The head of O&M uses the metaphor of a "gift" to describe how PMO is completing and wrapping up a new building to finally hand it over to O&M. One of the interesting things about a gift is the circumstance of not knowing, what is inside the wrapping. This is potentially very problematic when it concerns a new building. The finding that O&M does not seek to pull knowledge from the projects in a formal way, suggests that O&M would benefit from using another metaphor. O&M occasionally finds, that decisions made later in the project phases overrule the design standards, and this further underline that it is not sufficient to push knowledge to the project in the early stages and then sit back and wait to unwrap the gift at the hand-over.

Lack of human resources was, by the interviewees in both O&M and PMO, found to be the main reason for inconsistent use of the knowledge transfer mechanisms implemented in CAS. Lack of *collaboration*, supplementing *interaction*, such as mutual understanding, share the same vision and working as a team is possibly supplementary explanations. Figure 1 shows the possiblilty to have a broker to mediate between the sender and receiver in knowledge transfer, but it is interesting to notice that CAS according to our interviews does not use any kind of knowledge broker. CAS has started to introduce more formalised commissioning of the most technical complex building projects and a commissioning agent could act as a knowledge broker between the departments in CAS.

As described in the previous section, over the last years CAS has developed – and is still developing – various ICT-based tools. However, during the interviews the heads of the departments of CAS seemed to doubt the personnel's competences regarding using the existing ICT-based tools that assist the facilitation of KT between and within its departments. Consequently, there is a risk, that though knowledge is pushed into the repositories (see figure 3 and 4), it is seldom pulled out and consequently not applied in new building projects or to further develop FM. Four ICT-based tools were identified in CAS: Intranet, Project-web, BIM model and CAFM. As the idea is to transfer knowledge across phases of a buildings lifecycle, it is important that the employees knows not only how to push and pull knowledge from the tool dedicated to the life cycle phase they primarily are engaged with. However, even not fully developed, the ICT based tools play an important role regarding KT in CAS, both as far as they are increasingly developed and used, and as a symbol. The latter is important especially in CAS having no strategy concerning KM or KT.

A high level of knowledge transfer within an organization relies on both *interaction* and *collaboration*. In CAS, mechanisms have been implemented to support *interactive* cooperation. Meetings and development of documents have been mentioned in this paper as examples, see also table 2. Our research does not identify concrete mechanisms implemented to support collaborative cooperation. These activities intend to support mutual understanding, sharing of ideas and working together as a team with shared visions. Despite that initiatives to support the latter are not identified in our research, they are most likely to exist in CAS to a certain degree. Social events like a yearly employee trip and the annual Christmas brunch are examples. Moving the O&M and PMO to a shared office landscape is another initiative to support *collaboration*. However, CAS could benefit from thinking of interaction and collaboration as equally important.

DTU's main campus has a distinctive architecture that it might be important to preserve. One of the focus areas of O&M is the conservation of the campus architectural harmony as well as the avoidance of having buildings that are difficult or expensive to maintain. However, sometimes external architects in order to leave their footprints by designing a building that will differentiate from the existing, tend to ignore the original architecture and the general aesthetics of the buildings. Hence, it is essential for O&M to set some requirements, by using their knowledge from operation and maintenance of existing buildings, and transfer it into the new projects. The design standards intend to serve this focus, but the design standards are not always complied with in the new building projects. Thus, it is not sufficient for O&M to present the design standard in the beginning of the design phase. They need to follow up on their implementation during the whole design phase and go into a dialogue, if the design team has reasons not to follow the design standards.

6 CONCLUSION

This paper aimed to examine the knowledge transfer from building operations units to the construction project management in FM organisations to ensure appropriate performance of new facilities. According to the literature, the involvement of FM in a construction project from its early phases is crucial. In a new construction project, FM units can provide the project team in charge with valuable knowledge that supports the decision-making, ensuring that decisions with long-term benefits are made. For the facilitation of this knowledge transfer from the FM units to the project team, several tools and frameworks have been developed. ICT-based tools, such as intranet, project-webs, BIM and CAFM systems, play a key role in the facilitation of this knowledge transfer. However, these systems just serve as knowledge repositories that can store huge amount of data, information and knowledge.

The case organisation DTU Campus Service is an organisation that has been taking care of the operation and maintenance of campuses for many years; therefore, it possesses huge amounts of knowledge that can be used in the new construction projects. Over the last years, the importance of utilizing the existing FM knowledge has become apparent. For this reason, the management of the organisation has developed and established different tools and processes that facilitate the sharing of the existing knowledge throughout the organisation and from the FM unit to the project management of the new constructions. However, during the research it has been discovered that the case organisation has given more attention to the *interaction* activities, through the formation of a phase-gate project model and the development of several ICT-based systems, without focusing much on the *collaboration* activities within the organisation. This lack of collaboration and universal objectives within the case organisation creates several issues that lead to inefficient KT and frustration between the participants and impose the formation of a KM strategy.

Knowledge transfer within the case organisation has, according to the interviewees, improved over the last years, and the personnel are becoming aware of the importance of the knowledge transfer activities. The FM section leaders have created design standards to facilitate knowledge transfer from O&M department to the new constructions, which ensure that the FM requirements regarding the new projects are set for the project team to consider during the design phases. On the other hand, project managers ensure that all the available data and information that derive throughout every project phase are communicated to the FM sections, through the use of an ICT-based project-web. Both mechanisms of push and pull are implemented in CAS. However, it is found that the O&M department do not seek to pull knowledge from PMO in a formal way. One way to improve the knowledge transfer could be to appoint a person who could act as knowledge broker between O&M and PMO. This could be an internal mediator or an external consultant.

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Appendix 3

Paper C

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AAM version

A facilities manager's typology of performance gaps in new buildings

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Abstract

Purpose: The gap between the expected and actual performance of newly built facilities has been widely described in the literature as 'the performance gap'. Mostly, the performance gap appears to be synonymous with the energy performance gap. Little attention has been given to other performance aspects that facilities managers recognise as deficient in newly built or renovated buildings like for instance difficulties in operation and maintenance. This study contributes with a typology of performance gaps, with the aim to offer a more nuanced understanding of the term, where the interests of facilities management are in focus.

Method: The empirical data consists of four in-depth interviews, two focus group interviews and three workshops. Except for one workshop, the data collection took place in Denmark.

Findings: The study identifies 12 types of performance gaps of which 'higher energy consumption' is one. The gaps are interdependent and initiatives to reduce one type of gap can potentially lead to an increase in another. Furthermore, the study finds that the fatal (the most critical) gap is context-specific.

Implications: The findings of this study imply a need to change the way we previously have discussed the early involvement of the facilities management in design. The study shows that more involvement of FM is not necessarily better.

Originality: This paper is the first attempt to cover performance gaps of buildings from a holistic viewpoint and from the perspective of FM.

Introduction

Many resources go into the construction of new buildings. For instance in Denmark, the cost of new buildings in 2017 exceeded 110 billion DKK (14.5 billion Euros), and the number is increasing (Danmarks Statistik, 2018). However, when a new building is handed over to facilities management (FM), which is the organisational function responsible for the operational stage of the building, performance is not always as high as expected. This poses a problem, as the cost of operating the building by far exceeds the cost of constructing it (Hughes et al., 2004). Environmentally, the situation is similar: the operational stage is more resource-consuming than the construction stage (Maslesa et al., 2018).

With regard to energy consumption, several studies find a gap between the expected and actual performance of new buildings (Bordass, 2004; Gram-Hanssen & Georg, 2018; Mallory-Hill & Gorgolewski, 2018; Sunikka-Blank & Galvin, 2012). Other aspects, which FM has to deal with, are also observed to be deficient in some new buildings, for example lack of functionality, poor indoor climate, difficulties in operation and maintenance, and poor cleaning solutions. In 2017, the costs of building repair and maintenance in Denmark were nearly 80 billion DKK (more than 10 billion Euros) (Danmarks Statistik, 2018). Although work has been undertaken on different types of performances with potential gaps in new buildings, the vast majority of research on performance gaps of new buildings exclusively investigates the energy performance gap. No prior research is found on gathering the performance gaps, including - but not limited to - the energy performance gap, of special interest of the facilities managers. Research gathering different types of performance gaps is needed to understand the interrelation between types of performance gaps, and furthermore to stress that the energy performance gap is not always the most urgent gap for facilities managers to bridge. Based on literature, expert interviews, focus group interviews and workshops, this study presents a typology of performance gaps from the perspective of FM.

Literature review

The Energy Performance Gap

An online search in the scientific literature for ‘performance gap’ or ‘building performance gap’ revealed a large pool of research on unforeseen energy consumption in newly built facilities. The ‘energy performance gap’, or simply the ‘performance gap’, is consistently defined as the discrepancy between expected and actual energy consumption (Coleman & Robinson, 2018; Frei et al., 2017; Gram-Hanssen & Georg, 2018; Menezes et al., 2012; Sunikka-Blank & Galvin, 2012; De Wilde, 2014). The ‘reliability gap’ is another term occasionally used to describe the discrepancy between expected and actual energy consumption (Mills, 2011; Ornetzeder et al., 2016; Valle & Junghans, 2014), although the definition is the same.

Researchers have suggested that, despite awareness in academia of other performance parameters of a building with potential gaps, the energy performance gap is the most measurable and consequently the most debated (Lowe et al., 2018). Other researchers have found that measuring the performance gap is not that simple. Complicating factors include uncertainties in the design process, a lack of measure points in the completed building and the influence on performance of external circumstances such as outdoor temperature (De Wilde, 2014).

Whether measurable or not, the term ‘performance gap’ is almost always applied in the literature to mean a gap in energy performance. By contrast, the term ‘building performance’ is not exclusively about energy performance. In the following, literature contributing to a broader understanding of performance gaps is presented, regardless of the term ‘performance gap’ is mentioned or not.

Other types of performance gaps

Some prior studies have called for a definition of performance gaps that concerns more than energy performance. A comprehensive study of more than 240 references (Frei et al., 2017) found that the term is largely used to refer to the energy performance gap. Consequently, it is suggested that the term should be widened to also include indoor environment quality and operational expenses.

FM researchers have also turned their attention to unexpectedly high levels of operational expenses; they include Boge et al. (2018), who mention ‘unnecessarily high operation and maintenance cost, increased replacement rate and negative impact on core business’. Borgstein et al. (2018) support the suggestion of expanding the definition of performance gap to include not only energy, but also indoor environmental quality and occupant satisfaction. Borgstein et al. (2018) describe not meeting a performance parameter as a ‘performance failure’, rather than a performance gap.

The need to widen the definition of performance gap in facility evaluation is supported by authors investigating post-occupancy evaluation (POE) and building performance evaluation (BPE). As Tim Sharpe (2019) notes, user satisfaction is important: 'Buildings are, after all, inhabited by people'. Performance parameters such as comfort and health and wellbeing are suggested additions to the evaluation of buildings.

Oseland (2018) also places more emphasis on users or occupants and employs both quantitative and qualitative methods to evaluate building performance. BPE takes into account, not only energy, but also other aspects of building sustainability such as water consumption and indoor environment quality (IEQ) (Vischer, 2018). The book *Building Performance Evaluation* (Preiser et al., 2018) is a thorough elaboration of the concept that includes a variety of performance parameters.

A recent BPE study of nine Canadian 'green' buildings that evaluated their predicted and actual performance (Mallory-Hill & Gorgolewski, 2018) measured, in addition to energy use, occupancy rate, water use and IEQ, the argument being that these factors influence one another. For example, a higher occupancy rate influences water consumption. In two buildings, the actual occupancy rate was double the predictions made during the design stage. Moreover, the study questioned, whether the (energy) performance gap can be used to define, when a building is a 'failure', as different actors perceive it differently.

Loftness et al. (2018) have put forward the concept of total building performance, which is measured by six critical parameters, namely 1: spatial quality, 2: thermal quality, 3: air quality, 4: acoustic quality, 5: visual quality and 6: building integrity. Again, it is stressed that these parameters must be evaluated simultaneously, as they influence one another.

The need to focus on occupant satisfaction and usability is supported by a team of Norwegian researchers, who developed 'USEtool'. The tool follows five steps of evaluating usability of facilities and relies strongly on the involvement of the occupants, including walk-throughs and workshops (Hansen et al., 2011). The Leesman Index also deals with the usability of facilities, but focusing solely on the effectiveness of offices based on employee surveys (Leesman, 2018). Both the Norwegian USEtool and the Leesman Index consider exclusively users' perceived performance and experience and do not include performance parameters such as energy consumption or maintenance costs.

A literature review on evaluation tools for hospital facilities illustrates the fragmented research that hitherto has been conducted in the form of the 'Evaluation Focus Flower' (Fronczek-Munter, 2013). The flower is arranged according to the three qualities of architecture defined by Vitruvius, classic Roman author on architecture, translated as Beauty/Form, Durability/Technology and Utility/Usability. When organised in the 'flower', it is obvious that different evaluation concepts may overlap, but none covers all three qualities.

Lindkvist (2018) describes the difficulties facilities managers experience in the early operational stage of newly built facilities, by investigating the hand-over process from construction to operation. The project phase and the operational phase were found to overlap, with the result that contractors were continuously fixing problems during operation. Another study found that 'it took several years of refinement and tuning' to minimise the (energy) performance gap in the case of two buildings (Mallory-Hill & Gorgolewski, 2018). In those years of problem fixing and fine-tuning, there was a temporary loss of building performance.

The stage at which performance gaps are 'rooted'

As an obvious starting point for finding ways to bridge the energy performance gap, researchers have investigated at which stage of a building's life a gap is 'rooted'. Frei et al. (2017) mapped the causes found in the literature, pinning them down to three major lifecycle stages: a) design and planning: b) construction and commissioning: c) operation. Some researchers believe that decisions and actions during the design stage has the most impact on the future performance of a facility (Boge et al., 2018). Others find that the impact is greatest at the operational stage, arguing that the influence of occupant behaviour and the building's operation on the building's performance is often overlooked (Borgstein et al., 2018; Hong et al., 2017; Liang et al., 2019; Lowe et al., 2018). Other researchers conclude that causes for performance gaps may be found in each of the lifecycle stages, or in a combination of all (Van Dronkelaar et al., 2016; Way & Bordass, 2005).

Method

The study applied a qualitative research approach, where data was collected in three parts as shown on figure 1. Each part was completed, analysed and evaluated, before planning and conducting the following part. Furthermore, the study utilized an abductive approach, where themes that arose from the data were tested and further developed empirically and by consulting the literature (Alvesson & Sköldberg, 2009).

Figure 1 gives an overview of the empirical data included in the study in the order in which they were collected, namely parts 1, 2 and 3. The first part consisted of in-depth interviews with experts and was chosen with the aim of investigating practitioner's experience with the energy performance gap. Eight types of performance gaps were extracted from this data. A second row of data collection was planned and conducted to obtain further insights on practitioner's view on performance gaps. This part was based on findings from the first part of the data collection, namely the eight types. Two group interviews were conducted and analysed, leading to further development of the typology. To validate the findings, a third row of data collection was planned and conducted. With the aim of both disseminating the findings and getting the findings validated, three workshops were held. The individual data collection parts are described in the following.

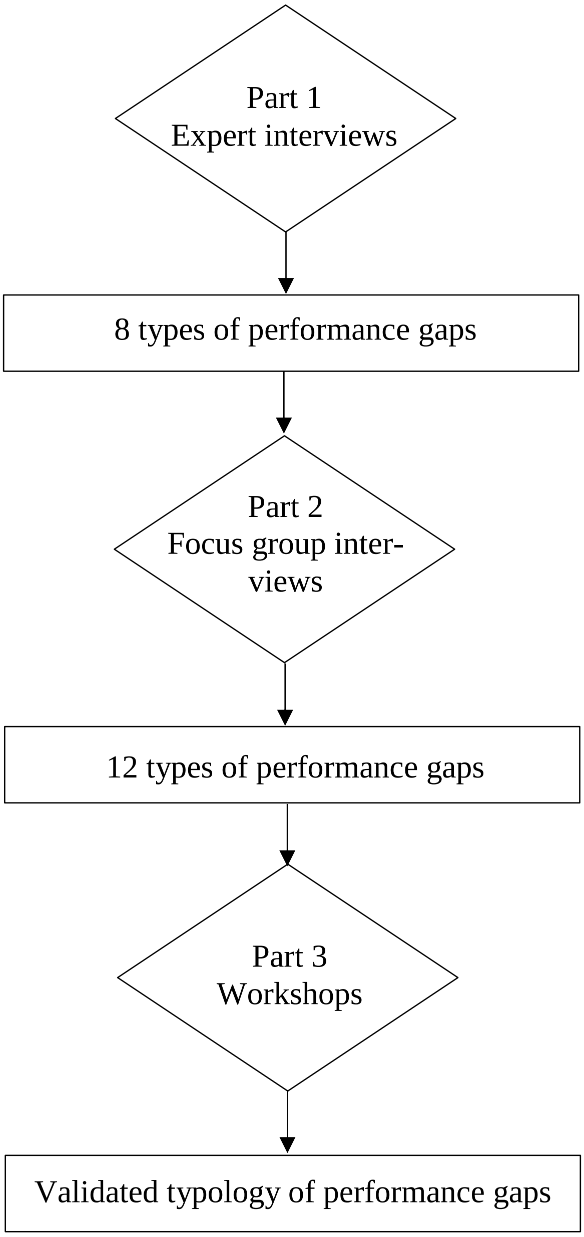

Figure 1 Data collection part one, two, and three.

Data collection part 1: Expert interviews.

Four semi-structured interviews with experts on building projects were conducted as the first part of data collection. Table 1 shows the distribution of interviewees and duration of the interviews. Purposive sampling technique was applied and interviewees considered being especially informative (Saunders et al., 2016) in respect to performance gaps in new buildings, were selected. Interviewees were experienced in large building projects, two from the building client side and two from the design side, to give maximum variation within the relatively small sample. The limited number of interviews in this first part was considered sufficient as it served as a base for the following steps rather than as results in itself.

The interviews had an exploratory nature (Saunders et al., 2016), in which the interviewer used a protocol as a checklist, but questions were posed in the order most likely to make the conversation flow naturally. The protocol included questions about the design process in general and in particular about the energy performance gap.

Table 1 Distribution of interviewees and duration of interviews

Role	No	Interviewees/Participants	Relevance to the study	Duration
Building designers	1	Building client consultant, self-employed.	Experienced project manager of large and complex building projects. Known for focusing on integration of operational knowledge in design.	64 min.
	2	Architect, owner of architectural firm.	Experienced in all stages of building projects, primarily large non-residential projects. Known for focusing on sustainability.	49 min.
Building owners (clients)	3	Director of a technique and environment division in a real estate and property investment company.	Experienced top manager for both building project divisions and operation divisions. Known for his involvement in the Danish ‘Building Green’ organisation.	53 min.

	4	Former project manager in a new building division for a large private company; now a self-employed building client consultant.	Experienced project manager for large complex building projects in an organisation with an internal operational division. 'Builds to occupy'.	50 min

The interviews were analysed by open coding (Strauss & Corbin, 1998) by using Atlas.ti® software. As such, the transcribed interviews were closely examined to detect every piece of text related to performance and performance gaps, in the broadest possible understanding. Then, codes with similar characteristics were conceptualised, resulting in eight concepts (Strauss & Corbin, 1998), hereafter named 'types' of performance gaps. The eight types formed a preliminary typology of performance gaps.

Data collection part 2: Focus group interviews

The second part consisted of two focus group interviews with the aim of further development of the preliminary typology. Focus group interviews were chosen to produce insights that would be less accessible without the discussion among interviewees (Kevern & Webb, 2001). An important finding from the first part of the data collection, expert interviews, was that the interviewed practitioners did not share the same focus on the energy performance gap as the literature. Consequently, the research team found it important that practitioners continuously informed the study. In both focus group interviews, the interviewees were part of a pre-existing group (Kevern & Webb, 2001) and none had been interviewed in the first part of data collection. The first group was four stakeholders of an ongoing research project about operational friendly building design, and had met several times before. The second group were three colleagues in a FM consultancy department of a large private consultancy company. Table 2 shows the participants, all from Denmark, duration and time of the focus group interviews. Participants were chosen for their knowledge on and experience with FM and trouble shooting in completed building projects. Like interviewees in part one, interviewees in the focus group interviews were chosen as they were expected to be especially informative to the study (Saunders et al., 2016).

In both focus group interviews, the preliminary typology was presented, after which participants discussed it, suggested changes, or pointed out the need for clarifications of the typology based on their practical experience. The typology was not changed from the first to the second focus group interview. However, suggestions on changes from the first focus group interview were passed on to the second focus group orally by the researcher conducting the focus group interview. Based on the focus group interviews, the typology was further developed.

Table 2 Focus group interviews

	No	Interviewees/Participants	Relevance to the study	Duration
Focus groups	1	2 associate professors at the Copenhagen School of Marine Engineers 2 FM consultants	Experienced with FM from teaching FM courses. Experienced with FM consultancy.	60 min.
	2	2 FM consultants 1 Commissioning expert	Experienced with FM in general and specialized in trouble shooting in newly completed buildings.	60 min.

Data collection part 3: Workshops

Part three of the data collection was conducted to validate the typology. As mentioned, a finding from the first part of the study was that practitioners and the literature do not share the same focus on the energy performance gap. For this final part of data collection, both practitioners and researchers were consulted for validation of the typology. Workshops as a research method was chosen to both validate the typology and give participants new insights on their own interests and in that way, the purpose was two-fold. The latter purpose resulted in easy access to participants, who willingly investigated their time in the workshop and participated actively. The facilitator was aware of the two-fold purpose, balancing the need for research outcome and the need for participant's outcome. The workshops were self-contained and participants were not asked to do preparations to the workshop (Oerngreen & Levinsen, 2017).

Workshop participants were chosen for their knowledge on building projects and FM, from either practice or research. As it was the case in the focus group interviews, participants of the three workshops were part of pre-existing groups. Table 3 shows the participants, duration and time of the workshops. There was an overlap of participants in focus group interview 2, and workshop 1. None of the participants had been interviewed in the first data collection part. Participants of workshop one, with two participants, and three, with five participants, were all from Denmark. Workshop two was held at an university in Norway with three international researchers as participants. The research team of this study knew that all three groups were in one way or another engaged in the topic of new buildings not performing as expected after hand-over. As such, they were chosen to be especially informative about the topic (Saunders et al., 2016).

A researcher from the research team facilitated all workshops. Like the focus group interviews, the researcher first gave a presentation of the study and the developed typology and asked participants for comments and questions. Additionally, the workshop participants were asked to do two exercises about the typology together as a group. The researcher introduced the exercises, one at a time, gave instructions during the exercises and answered questions, but did not participate in the exercise. Audio recording, photos and notes documented the workshops. Summaries were made afterwards.

Table 3 Workshops

	No	Interviewees/Participants	Relevance to the study	Duration
Work-shops	1	2 FM consultants (same as Focus group 2)	Experienced with FM in general and specialized in trouble shooting in newly completed buildings.	60 min.
	2	3 FM researchers at Norwegian University of Science and Technology (NTNU)	Hold knowledge on FM, design and construction projects.	90 min.
	3	5 FM staff members at Campus Service, DTU	Experienced with project management of building projects (3). Experienced with trouble shooting in completed buildings (2).	90 min.

Working with the 12 types of performance gaps during the two exercises fulfilled the two-fold purpose. First, it made the participants familiar with the types. Second, as the participants discussed how to answers the exercise, they gave examples on how they had experienced the individual types.

The first exercise was about the ‘rooting’ stage of the individual gaps, that is, when decisions or actions were made causing the later presence of a gap. The three stages of planning/design, construction and operation (see Literature review) were applied. Twelve labels (Post-its®), each with a number from one to twelve representing the performance gaps, were handed out to the participants. They were asked to discuss, when in the lifecycle each performance gap was most likely to be ‘rooted’. Finally, they were asked to place the labels on the table top under the headings for the three stages, as they saw relevant.

In the second exercise, participants were asked to place the same labels, each representing a type of gap, in accordance to which parameter of quality, time or money, they found most fundamental in avoidance of a gap. The third and largest group did not do the second exercise due to time limitations.

The purpose of the exercises was to get rich discussions about the gaps among participants to validate the typology, rather than it was the purpose to get their answers to the exercises. Consequently, outcome of the exercises were not included in the findings.

Findings

Expert interviews

In the expert interviews, the respondents were asked, if they had experienced a performance gap. As this was the initial stage of the study, the interviewer posed the question only in relation to energy. None of the four interviewees gave a clear answer to this question. Two (one designer, one building client) confirmed that there often is a gap, but the size is difficult to measure. One interviewee answered that it was beyond his expertise, and one answered the following: '*Actually, I am afraid that we really do not know… when a new building with a predicted energy consumption of x kilowatt hours is handed over… then there is no one who verifies, if that actually remains the case five years on*' (building client).

Having answered whether they had observed a performance gap or not, the interviewees on their own initiative, commented on the interviewer's focus on energy performance. One interviewee (architect, partner in an architectural firm) said: *'When we talk about "operation", we often mean energy consumption. That is what it traditionally is ... but the real "operation" is about you and me! It is about the employees being well and thriving ... They are the real operation cost.'* Comments such as this inspired the researchers to investigate other performance aspects potentially not fulfilled in new buildings mentioned during the interviews. Further review of literature was done, this time including literature investigating other performance parameters failing in new buildings than energy performance. The following eight types of gaps were detected by analysing the transcriptions.

- Higher energy consumption
- Higher operational costs
- Higher maintenance costs
- Operation start-up loss
- Disappointing ”user experience”
- Unsatisfactory indoor climate
- Mismatch with business case
- Double operation or no operation

Focus group interviews

The participants of the two focus group interviews shared the opinion of the interviewed experts that gaps of building performance concerns more parameters than energy. From the focus group interviews, it was found that: A) Lack of flexibility is another performance parameter found ‘gapping’ in new built buildings. B) User experience is too broad a term to cover experience of both FM staff and core business staff. C) Not meeting legal requirements has been experienced by the interviewees to be a problem in new buildings. D) Expenses changed from Capex to Opex is another challenging issue, when new buildings are handed over to FM. The issues A, B, and C were brought up by interviewees in the first focus group interview. Interviewees of the second group agreed upon A, B, and C and furthermore suggested issue D.

A typology of 12 performance gaps was developed, see figure 2, based on both expert interviews, review of literature and focus group interviews.

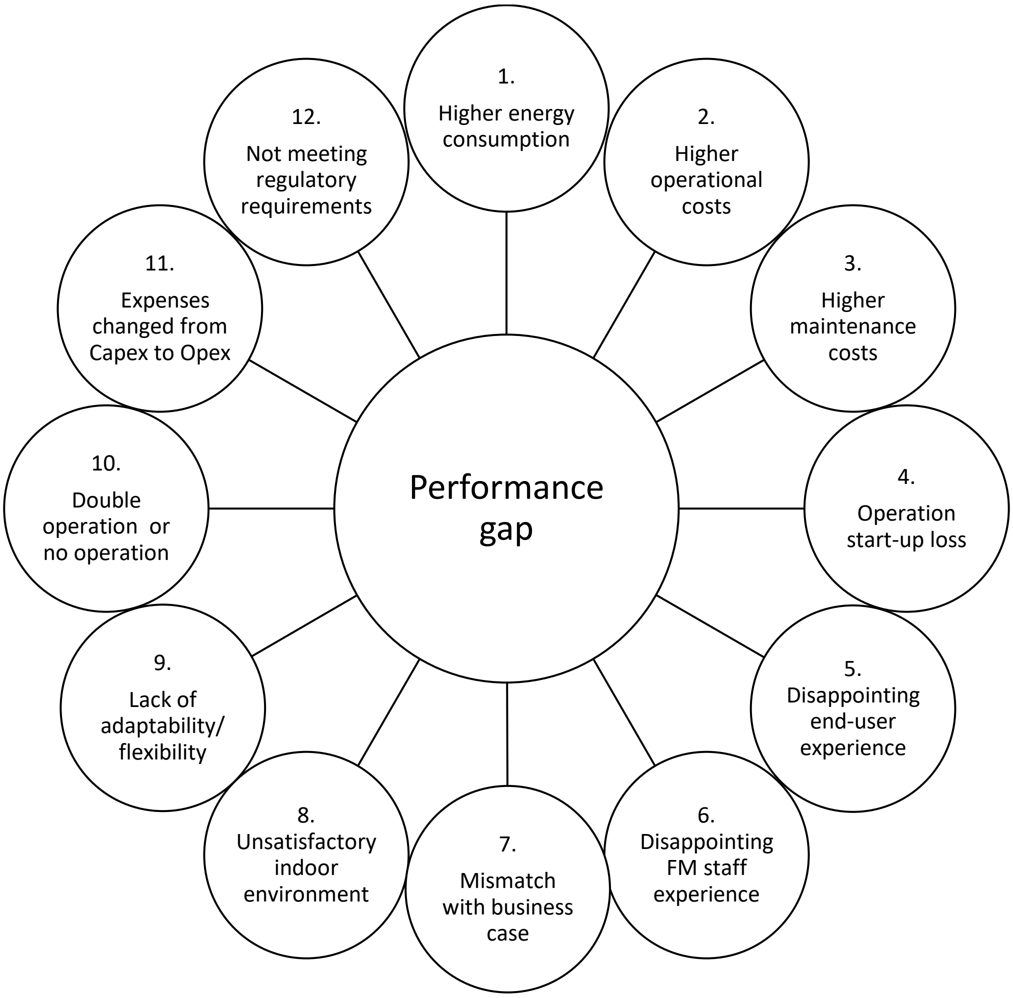

Figure 2 Typology of performance gaps in newly built buildings – from a FM perspective.

Workshops

The third part of the data collection, workshops, validated the 12 types further. The participants provided supplementary examples of the 12 gaps, but none that led to changes in the typology. A brief description and examples gathered in all three data collection parts are given in the following.

Gap 1 is ‘higher energy consumption’ and the one the literature investigates by the terms ‘building performance gap’ or ‘reliability gap’. Energy goes into heating, cooling, ventilation and lighting of buildings. Furthermore, energy goes into the processes taking place in buildings, for example related to IT and producing goods.

Gap 2 is ‘higher operational costs’. Operation is here understood as cleaning, waste handling, supplies, caretaking, monitoring and daily supervision. The gap appears when costs for these services are higher than estimated or expected. Both the interviewed experts and workshop participants mentioned examples of this. One interviewee referred to a large commercial project in central Copenhagen. In the operation stage, they had experienced an unexpected cost of cleaning the surroundings every morning due to the lively nightlife of the neighbourhood. In the same project, window cleaning were more expensive than expected, as it had to be done by a rope climbing (rappelling) team.

Gap 3 is ‘higher maintenance costs’. This gap occurs, if building parts or installations need more frequent maintenance than expected, if spare parts are more expensive than expected, or if the part in need of maintenance is difficult to access or the spare part is difficult to get. A workshop participant, referring to a recent project he was involved in, gave the following example: *“… That is, for example, when you make 380 fire shutters that are impossible to service, and you then need to spend two months each year doing it”*.

Gap 4 is ‘operation start-up loss’, which primarily is loss of energy due to difficulties in the early operation stage, often caused by lack of or insufficient commissioning of installations. An example is when lowering the room temperature outside working hours is not possible yet due to lack of programming of the building management system.

Gap 5 is ‘disappointing end-user experience’ and occurs, when a certain user experience concerning functionality, aesthetics, or convenience is not met. An example is, when the design of an expensive hotel or restaurant does not meet expectations of a certain aesthetic level. Another example is, when the layout of a working space, for example an office floor, causes inconvenient workflows, or offers too few meeting rooms.

Gap 6 is ‘disappointing FM staff experience’. This is similar to gap 5 and concerns both aesthetics, functionality and convenience. However, particularly the focus group participants argued that FM staff experience difficulties that are different from other user groups. Examples given by the focus group participants include too small or poorly located cleaning rooms.

Gap 7 is ‘mismatch with business case’. This occurs, when the building does not meet the conditions, which were anticipated in the business case. Examples are less parking space for cars than initially anticipated, less hotel rooms than anticipated, or less office space to sublet than anticipated. The gap can appear stepwise during the design stage, but it can also unexpectedly appear in the operation stage.

Gap 8 is ’unsatisfactory indoor environment’. This covers unexpected challenges relating to the thermal indoor climate, acoustic environment and air quality. A workshop participant described challenges with noise from the ventilation in 80 percentages of the rooms in a newly built large multi-functional building.

Gap 9 is ‘lack of adaptability/flexibility’. This gap occurs, when a building is difficult to adapt to changing needs during the facility’s lifetime. A focus group interviewee gave an example of a recent case she had been involved in, where the number of staff in a large organisation was dramatically reduced. Comprehensive conversion of the building and in particularly the technical installations was needed to make it possible to sublet the now redundant office space.

Gap 10 is ‘double operation’, which occurs when two facilities are needed instead of one during occupation or relocation. Alternatively, when the facility is handed over (delayed or not), but the facility is not suitable for ‘business’ yet. An example given by a focus group interviewee concerned moving the large consultancy firm in which she was employed to a new built headquarter. To ease the relocation process, 200 employees were moved at a time, followed by another 200 a week later and so forth. Stretching the move caused double operation, as services such as cleaning and catering were needed in both the new and the old headquarters at the same time.

Gap 11 is ‘expenses changed from Capex to Opex’. This gap occurs, if the operation budget needs to cover expenses (Opex – operational expenditures) in relation to the new building, which were expected to be included in the building project and its budget (Capex – capital expenditures). This can be caused by the need for cost cutting due to budget overrun for the building project or it can be a matter of unclear communication about what is covered by the budget of the building project. Examples of the latter are expenses to blinds, furniture, way-finding signs, and keys.

Gap 12 is ‘not meeting regulatory requirements’. This occurs, when a building does not meet requirements from authorities. An example is, when the building does not pass acceptance check by the fire authority, before the planned opening day, or the authority in charge of working environments withholds its approval of the workplace.

The fatal gap

The types are organised from 1-12 in figure 2 in the order in which they appeared from the initial analysis of the four expert interviews and focus group interviews, not according to importance or cost or any other factor. Already during the first part of the data collection, the expert interviews, it was clear, that the importance of the gaps depends on the specific project. In a new office building, the fatal gap is more likely to be ‘disappointing user experience’ (gap 5) or ‘unsatisfactory indoor climate’ (gap 8), rather than ‘higher energy consumption’ (gap 1). The following is an example that one of the interviewed experts gave from a hotel project (building client consultant):

‘*When you design mirrors from floor to ceiling in a hotel room… housekeeping has to bring in a stool [to stand on] when they are cleaning ... That takes one additional minute per room… Add 800 rooms, at an hourly rate of 150 DKK, and you find that it costs around one million DKK every year in operation.*’

From the quote, it is impossible to judge, whether mirrors from floor to ceiling are the right or the wrong design solution. If ‘disappointing user experience’ (gap 5) would be fatal, then it might be the right design, but if ‘higher operational cost’ (gap 2) would be fatal, then it is a wrong decision. Consequently, the typology cannot be organised according to importance, as this is context-specific. The perception of which performance gap is fatal also depends on the responsibility and interest of the facilities manager. For instance, some have responsibility for the overall business case and both for Capex and Opex, while others only have responsibility for Opex. Therefore, the perception of the importance of ‘mismatch with business case’ (gap 7) and ‘expenses changed from Capex to Opex’ (gap 11) will probably be very different and contradicting.

Gaps are interlinked

When the fatal gap (there can be more than one) is identified in a project, it is tempting to focus solely on bridging this particular gap. However, this is not necessarily advisable, as the gaps are interlinked. They potentially affect one another in at least three ways. First, if one gap closes, another may open. Second, there may be a snowball effect, where one gap is causing another gap. Third, the gaps may affect one another when bridging one gap automatically leads to - if not bridging then at least - narrowing another gap.

One of the experts provided an example illustrating, how closing one gap can open up another. He described a large building project, where oil-treated wooden floors were chosen. This design solution causes ‘higher maintenance costs’ (gap 3), as floors need to be re-treated with certain intervals. However, in the example given, it served the purpose of meeting a certain end-user experience. Since ‘disappointing end-user experience’ (gap 5) was considered fatal in this specific project, wooden floors was considered appropriate, despite an increase in maintenance costs. Another example provided by one of the interviewed experts, concerned end-users that are not given the possibility to open doors or windows manually. This design solution was chosen to avoid ‘unsatisfactory indoor climate’ (gap 8), potentially also ‘higher energy consumptions’ (gap 1). However, it may cause ‘disappointing end-user experience’ (gap 5), or even ‘higher maintenance costs’ (gap 3), if windows or doors are damaged, because they are forced to stay open with wedges.

Participants of the third workshop gave an example illustrating, how gaps can affect one another as a snowball. They had recently moved in to their new built office building. After they had occupied the building, it was found that the acoustic indoor climate did not meet the regulatory requirements. Different actions to reduce noise were taken, including closing a large lunch area on the ground floor with an open connection to the office space on the floors above. Assumingly, providing the employees a common lunch area was part of the business case – and later a part of the building brief. Thus, ‘not meeting regulatory requirements’ (gap 12) caused a ‘mismatch with the business case’ (gap 7) as the common lunch area was removed.

Design of daylight in buildings was mentioned by one of the interviewed experts as an example of how bridging one gap automatically leads to - if not bridging then at least - narrowing another gap. She argued that the right design of daylight can prevent the gap 'unsatisfactory indoor climate' (gap 8) together with 'higher energy consumption' (gap 1). Furthermore, proper daylight design can bridge the gap of 'unsatisfactory end-user experience' (gap 5).

Workshop two was held with researchers, the others with practitioners. No significant difference between these two types of participants were found. This is unexpected, as the literature review showed that the focus of research and practise is not identical. The typology was discussed without suggestions for changes in all three workshops. Furthermore, the discussions and finally the lay out of the labels in the workshop exercises were to a large extend similar in all workshops.

Discussion

Performance is more than energy

In the literature, the performance gap is often synonymous with the energy performance gap. In the light of this study, this narrow definition of the term is problematic. Furthermore, the literature deals mostly with the gaps individually, or in best cases a few at a time. It is understandable, that in-depth research must investigate one issue at a time, to achieve a thorough understanding of each of the gaps. When it comes to practise, an individual treatment of the gaps must be avoided or supplemented with a holistic assessment.

Other performance gaps than energy

The reviewed literature covered several of the performance gaps included in the typology. The most commonly mentioned concerns gap 8 'unsatisfactory indoor environment', and there is a distinct research discipline focusing on indoor climate. Gap 2 and 3 concerning 'higher operational cost' and 'higher maintenance cost' is mentioned in FM-related literature for instance by Boge et al. (2018), but has not been researched much. Gap 4 'operation start-up loss' is mentioned by Lindkvist (2018) but has not been researched much, either. Gap 5 concerning 'disappointing end-user experience' is researched widely in the literature on building performance evaluation and POE. Gap 6 concerning 'disappointing FM staff experience' is much less researched but covered by some FM-related research like Jensen (2012) and Rasmussen et al. (2019). Gap 7 concerning 'mismatch with business case' is hardly covered as such by research, but there might in the context of construction management be some research relating to this gap. Gap 9 concerning 'lack of adaptability/flexibility' has not either been researched much as such, but there is a field of research on adaptability/flexibility of buildings often of a normative character. Gap 10 concerning 'double operation or no operation' is as far as the authors know not covered at all in earlier research. Gap 11 concerning 'expenses changed from Capex to Opex' is not mentioned in the reviewed literature, but it might be covered in limited degree in some construction management research. The last gap 12 concerning 'not meeting regulatory requirements' was not found specifically in the reviewed literature, but it is probably part of some research on energy performance gap as well in other specialist literature for instance in relation to indoor climate and fire protection. Nevertheless, this paper is the first attempt to cover performance gaps of buildings from a holistic viewpoint and from the perspective of FM.

Building clients and facilities managers have different perspectives

There is a need to examine building projects from the facilities manager's perspective, because it differs from the perspective of the building client. In the perspective of the building client, criteria as cost and time of the project are often crucial. In the perspective of the facilities manager, cost and time of the building project itself is less important. In a number of cases, the building client is a part of a FM organization. In such cases, theoretically, the aim and focus of the building client and the facilities manager is identical. However, in practise, the building client staff and the operational staff often are divided in two sub-organizations within the larger FM organization (Jensen, 2012, Rasmussen et al., 2019). The typology presented here can serve as a base for the collaboration between the two and illustrate the different perspectives of the two roles.

The performance gaps can be used to develop a common understanding and manage of expectations among stakeholders of what is most important in a new building projects and to identify critical success factors that can form a basis for communicating priorities to project management and designers in the early planning phase.

Implications for the facilities manager's role

The findings of this study imply the need to change the way we have previously discussed the early involvement of the facilities manager (Jensen, 2012; Rasmussen et al., 2019). The study shows that more involvement is not necessarily better. When facilities managers are involved in the design process, they must realise a) that the fatal gap is project specific, and b) how the gaps are interconnected, as involving them can otherwise be counterproductive. By trying to close one gap (the one that is closest to their niche in FM), they risk opening up another.

Nuancing the debate by developing the 12 gaps shows that a very different kind of knowledge on the part of the facilities manager is needed to bridge the different gaps. It may even be that his or her knowledge is not needed to close some of the gaps. With the typology, practitioners and researchers can start to discuss what kinds of skills and competences are needed to close the individual gaps, and, perhaps most important, which actor(s) can help to balance the 12 gaps, to ensure that involving FM to close one type of gap does not open up other gaps.

Limitations and generalisation

This study was of a qualitative nature, which has been a strength to be able to develop and validate the typology of performance gaps. However, it also gives the limitation that we cannot say anything specifically about, which gaps are most and least important (fatal), besides general statements about the gaps being context-dependent.

Another limitation is that the data collection mostly took place in Denmark and mostly involved Danish experts. The only exception was workshop two, which took place in Norway and involved researchers from Ireland, UK and Norway. It can be noted that this workshop did not show any disagreement with the typology. This support our expectation that the typology applies to other countries besides Denmark. We also found support for this in one of the expert interviews (Architect, partner in an architectural firm):

"When we look back (...) at [complaint] cases with customers: They are because of problems with ventilation and the indoor climate, the FM oriented (...). These customers, they don't get the solution they want. (...). It's not just in Denmark, it's international, also with our international business partners."

Conclusion

The study shows that practitioners are greatly concerned about several potential gaps in performance other than energy gap. The presented typology includes 12 performance gaps from a FM perspective with the energy performance gap primarily being covered by literature. The energy performance gap is off course still very important, but the study demonstrates that attention must be paid to other gaps, too, and in particular, that focusing solely on the energy performance gap poses the risk of causing other gaps. Building clients must take actions to ensure that the demand for low energy consumption in new buildings does not lead to the neglect of other types of gaps.

The consequences of the gaps are context-specific and vary from project to project. Thus, a hierarchical organisation of the types of gaps is not appropriate, as all gaps can be equally important until they are related to specific projects. The 12 types of gaps are highly interconnected. Actions to bridge one type of gap can help bridge other gaps, too. However, actions to bridge one gap also carry the risk of opening up other gaps. Solving each gap requires specialised knowledge and deep insight into the individual topics of the 12 gaps. Thus, a broader understanding of all of the twelve gaps is needed in each project.

Policymakers should ensure that ambitions to lower energy consumption in new buildings is not causing other types of performance gaps. At the present, there is an overwhelming focus on reducing energy consumption in many countries and huge funding has been allocated for instance by the EU to energy related research and development; particularly concerning new buildings. This study indicate that there is a need to put more political attention towards building operation and to building performances in other terms than just energy.

Further research

Based on the typology, further research and development on possible ways to bridge the gaps and mitigating actions to avoid them are recommended. The skills and competences needed to close the different gaps should also be investigated.

The performance gaps have consequences, which is the reason why they are worth investigating. They have consequences on either the core business, the life quality of those who occupy the building, and the environment of the planet. We suggest further research to investigate, how often the different gaps occurs, the consequences and the related cost of the gaps. Moreover, we hope researchers in the future will investigate the ‘fatal gap’ more, as it may be possible to generalize which gaps are fatal in certain types of buildings.

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Appendix 4

Paper D

The legacy from construction projects to facilities management in Denmark: The good, the bad and the ugly

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ABSTRACT

Purpose: When construction projects are handed over to facilities managers who are in charge of operating the new facilities, things are not always as easy as could be expected. The scientific literature describes examples like discrepancy between the expected and the actual energy consumption, disappointing indoor climate and continuous troubleshooting after hand-over.

These issues are causing facility managers difficulties in new buildings. This is problematic as it has a negative impact on the costs, the people and the environment. Studies have been carried out on each of these important aspects. However, most studies have a specific focus on one issue.

The purpose of this study is to explore a broader range of FM difficulties in new buildings, with the aim of ranking which difficulties are most and least experienced by facility managers in new buildings in Denmark.

Methodology: Our study is based on a national web-based questionnaire survey among FM practitioners in new buildings in Denmark. The identified FM difficulties in new buildings are ranked by mean value to find the most and least experienced.

Key findings: The study shows that most frequent experienced difficulties are related to the quality of operation and maintenance material and drawings handed over from construction to operation. Unexpected high energy consumption due to lack of commissioning of the technical installations, and indoor climate difficulties are other often experienced issues. The least frequent experienced difficulties concern the layout and functionality of both FM space (as kitchen, cleaning room and technique rooms) and core business space (as offices, meeting rooms, and teaching rooms).

Intended impact of the study: The study informs building clients, design teams and facility managers about which difficulties they need to pay extra attention to in future building projects. To researchers, it suggests further research to find solution for the most experienced difficulties. Furthermore, our research suggest further research to investigate in the consequences of these frequently experienced difficulties and how they can be avoided in future construction projects.

Paper type: Research Paper

Keywords: FM, Facilities Management, FM difficulties, performance gaps, construction projects, building performance.

1 INTRODUCTION AND BACKGROUND

Construction of new buildings are heavily resource consuming, regarding both financial, human and natural resources. In Denmark more than 110 billion DKK (14.5 billion Euros) went into construction of new buildings in the year 2017 (Danmarks Statistik, 2018). Operating the new buildings are even more resource consuming, both financially (Hughes et al., 2004) and environmentally (Maslesa et al., 2018). New buildings offers a unique possibility to optimize the operation stage, by taking operation into consideration during design and construction (Boge, 2017). However, when a new building is handed over to facilities management (FM), responsible for the operational stage of the building, previous studies show, that operation is not always as unproblematic as could be expected. We will shortly introduce some of these challenges addressed by research. They include energy consumption, operation and maintenance (O&M) cost, impact on core business, end user satisfaction, and indoor climate.

A large pool of scientific literature describe a discrepancy between the expected and actual energy performance of new buildings, known as the energy performance gap (Gram-Hanssen & Georg, 2018; Mallory-Hill & Gorgolewski, 2018; Sunikka-Blank & Galvin, 2012) or the reliability gap (Mills, 2011; Ornetzeder et al., 2016).

Sustainability is the main focus of Building Performance Evaluation (BPE) which takes into account not only energy consumption but also other aspects such as water consumption and Indoor Environment Quality (IEQ) (Vischer, 2018). Also the concept Total Building Performance (TBP) (Loftness et al. 2018) goes beyond energy consumption by introducing six critical parameters in new buildings. They include IEQ, spatial quality, visual quality and building integrity.

Boge et al. (2017) adds further parameters to be considered in building projects. Referring to Bjørgberg, he mentions the risk of ‘unnecessarily high operation and maintenance cost, increased replacement rate and negative impact on core businesses’. Borgstein et al. (2018) describe a number of performance failures in new Brazilian buildings. They include higher energy consumption, poor indoor environmental quality and lack of occupant satisfaction.

In a study of the hand-over process from construction to operation, Lindkvist (2018) finds that an overlap of the construction and operation phases is causing FM difficulties, as contractors continuously need to fix problems during operation. The finding, that there is a need for continuously ‘fine tuning’ after a building has been occupied, is supported by recent study by Mallory-Hill & Gorgolewski (2018).

Clearly, research has already identified a large number of challenges that FM face during operation of new buildings. As it seems that the term ‘building performance gap’ is considered to concern only energy performance, we use the term ‘FM difficulty’ as an overall term to address a broad range of challenges.

Although work has been undertaken on different types of FM difficulties in new buildings, no prior research is found gathering a broader range of FM difficulties in one study. Looking at different FM difficulties together offer an impression of which difficulties are least and most experienced in new buildings. With this knowledge, building clients, design teams and facility managers involved in building projects are given the opportunity to learn from the past and discuss how FM difficulties outlined in this study can be prevented in future projects.

To guide our research study, we formulated this research question: Which difficulties do facility managers in Denmark most frequently experience in new buildings in Denmark? And which difficulties are least experienced?

2 METHODOLOGY

In order to answer our research question, we applied the methodology outlined by Burns et al. (2008), suggesting the following steps.

Sampling

We applied a nonprobability sampling where individuals where selected because they met the sample criteria of being employed in a FM organization managing a newly built or rebuilt building. Since this population is not accessible as a unit, we distributed the questionnaire trough different channels reaching a broader population of facility managers (and potentially others). The size of the population (employees in a FM organization with a newly built or rebuilt building) is unknown to us, thus is the respondents rate unknown. Distributions channels were: 1) e-mails to the research team's professional network of FM practitioners, 2) newsletter (by e-mail) to the members of Danish Facilities Management Association, 3) newsletter (by e-mail) to members of the FM network of the Danish Association of Marine Engineers, 4) Linked-in posts.

Item development

To start the generation of items to include in the questionnaire we conducted a literature study. This resulted in 21 items spread on 6 categories. We consider an item 'a FM difficulty in new buildings', for example 'poor indoor climate – too cold'. We discussed the 21 items found in the literature with FM practitioners attending a FM course at the Danish Technological Institute. They were within the intended population and contributed with additional items based on their experience.

The final number of items were 35, spread on the initial 6 categories as shown in table 1. Since short questionnaires are more likely to have an increased number of respondents than longer ones (Burns, 2018), we only added 2 background question.

Table 1: Categories of FM difficulties in new built buildings.

No.	Category	Number of items
1	Indoor climate	5
2	O&M of technical systems	5
3	O&M of buildings	7
4	Sustainability	6
5	Functionality	5
6	Others	7

Response format

The questionnaire consisted of 4 parts: First a background question to verify if respondents were within the intended population, yes or no. Second, the 35 difficulties spread on 6 categories (one category on one page). We asked respondents to indicate their experience with each of the 35 difficulties on a four-point Likert scale: 1: Never experienced, 2: Experienced to a lesser degree, 3: Experienced to some degree, and 4: Experienced to a high degree. A fifth choice was "Do not know/not applicable (N/A)". Furthermore, we included a "free text" option at the end of each category, where respondents had the opportunity to describe other experienced difficulties. In the third part, we asked respondents to describe in free text what they found most successful in their new building. Finally, we posed the second background question (figure 1) asking respondents to indicate by multiple choice which statement best described their work tasks.

We allowed respondents to move on to next question without having answered previous questions.

Questionnaire composition and testing

The software Qualtrics ® was used to publish and administer the web-based questionnaire. The questionnaire was pilot tested by the same group who had been part of identifying the 35 items (course participants). Another five persons with experience with FM in new buildings tested the questionnaire. The testing resulted mostly in correction of unclear language. Moreover, test persons were asked to record the time they spend on completing the questionnaire. Questionnaires completed as part of testing were not included in the results.

As introduction to the questionnaire, a brief text described the purpose of the study, the length of the questionnaire, and stated complete anonymity for respondents. The questionnaire was open for answers from October to December 2018. Both introduction text and questionnaire were in Danish.

Analysis

To answer our research question, we calculated the mean value of the respondents' indication on the likert scale of each of the 35 items. N/A answers were not included in the mean value. We then organized the items by their mean value (table 2). We interpret that items with the highest mean value (nearest '4: experienced to a high degree') are the most frequently experienced and thereby "the bad or the ugly", whilst items with the lowest mean value (nearest '1: Never experienced') are the least frequently experienced and thereby "the good".

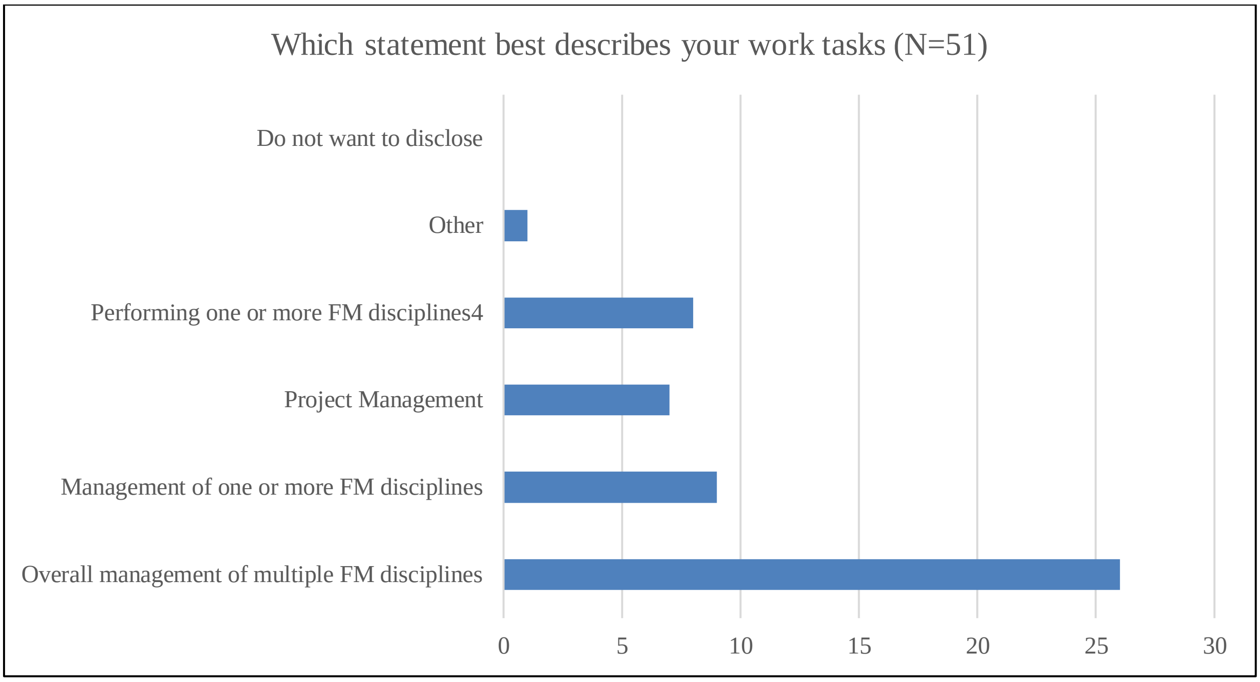
3 RESULTS

Respondents

Answers to the first background question showed that 76 FM practitioners in new buildings (or old buildings recently substantially rebuilt) filled in the questionnaire. Furthermore, 29 respondents (105 in total) outside the intended population completed the questionnaire. Due to the limited number of background questions, we do not know to what extend they are similar to the other 76 respondents (Burns, 2008) and we omitted their answers from the results.

The second background question, posed in the end of the questionnaire, shows that the majority of the respondents who answered this question (N=51) has FM responsibilities of one or more FM disciplines as shown in figure 1.

Figure 1: Respondents' work tasks



Ranking of the 35 difficulties

Table 2 shows the 35 difficulties ranked by mean value (see 3.5 Analysis). Number one (top of table 2) is the difficulty with the highest mean value whereas bottom row, number 35, is the least experienced difficulty. The number in the first column refers to the rank (by mean value), second column refers to the six categories (see table 1). Third column is the specific difficulty, translated to English. Fourth column is the number of respondents who ranked the specific difficulty, in parenthesis the number without N/A.

Table 2. The 35 difficulties ranked by mean value

Rank	**Category /No.**	**Difficulty**	**N=**	**Mean value**
1	6.3	Inadequate or poorly structured O&M material e.g. missing information in the O&M software/ lack of upload of information to the software	51(47)	3,36
2	4.6	Unexpected high energy consumption due to the lack of commissioning of the technical installations	52(51)	3,24
3	6.4	Inadequate or not updated blueprints to the FM-staff	51(49)	3,18
4	3.2	Unexpected costly og difficult cleaning of windows externally og internally due to lack of accessibility	52(48)	3,06
5	6.1	Unexpected operating investments due to the change of costs from Capex to Opex	51(49)	3,04
6	1.1	Poor indoor climate – too hot	58(56)	3,04

7	1.4	Lacking or difficult coordinated control of heating and cooling	59(57)	3,00
8	3.7	Damage to doors and windows forced open by the users using e.g. wedges	52(50)	2,98
9	1.2	Poor indoor climate – too cold	59(57)	2,86
10	2.2	Unexpected costly O&M of technical installations due to limited access or costly spare parts	54(52)	2,83
11	4.1	Higher energy consumption than expected	52(40)	2,83
12	3.1	Unexpected costly cleaning of surfaces due to choice of materials, e.g. on floors and walls	52(46)	2,80
13	2.4	Inappropriate or expensive options for changing light sources and servicing light fixtures	54(49)	2,78
14	3.6	Difficult or expensive change of building components – e.g. windows and façade panels	52(48)	2,75
15	2.3	Floors in wet rooms with incorrect or defective slope and / or drainage	54(52)	2,62
16	2.1	Limited possibility to use auxiliary tools such as lifts due to interior design or construction	54(48)	2,60
17	1.3	Poor indoor climate - draught	58(57)	2,60
18	1.5	Poor acoustic indoor climate - noise from people, machines, surroundings	59(57)	2,60
19	3.3	Unexpectedly rapid wear and tear of floors due to inappropriate material selection	52(48)	2,58
20	5.1	Inappropriate location and / or layout of kitchen, cleaning room, waste room	52(49)	2,43
21	5.2	Inappropriate location and or layout of rooms with technical installations	52(49)	2,41
22	5.5	Restricted adaptability of office spaces to changes e.g. during to organizational changes	52(45)	2,40
23	4.2	Too few energy og water meters	52(44)	2,40
24	5.4	Lack of opportunity to use rooms for multiple purposes during the day	52(47)	2,36
25	6.2	Lack of compliance on regulatory requirements, fire prevention demands, safety requirements etc.	51(50)	2,32
26	4.4	Difficult waste handling	52(45)	2,31
27	2.5	Poor physical working conditions for the FM-staff. E.g. reduced ceiling height og poor daylight conditions	54(53)	2,30
28	3.4	Unexpected or fast discoloration/ patina of *internal* building components	52(49)	2,27
29	4.3	The lack of bicycle parking, poor accessibility of the bicycle parking and/or lacking shower facilities for the bikers	52(45)	2,24
30	3.5	Unexpected or fast discoloration/ patina of *external* building components	51(47)	2,23
31	6.5	Unexpected need for double operation due to delay in the construction project	51(46)	2,22

32	4.5	Lack of automatic control of the light	52(51)	2,06
33	5.3	Inappropriate location or interior design of the core facilities of the enterprise e.g. class rooms, offices, meeting rooms and production facilities	52(49)	2,00
34	6.7	The architecture does not fulfill the function or mirrors the culture of the enterprise	50(47)	1,89
35	6.6	The architecture is not aligned with the brand of the enterprise	50(43)	1,72

The good

Starting from the bottom, the three least experienced difficulties concern architecture and layout design (table 2, rank 35, 34 and 33). This is supported by the free text answers to the question "What do you consider to be most successful in your new building?" where 6 out of the 17 statements, described successful architecture or layout. Examples are *"Creating a completely new unity"* and *"Super nice and functional building; new and fresh without being showy"*.

"Lack of automatic control of the light" (table 2, rank 32) and "Unexpected or fast discoloration/ patina of both *internal* and *external* building components" (table 2, rank 30 and 28) are also little experienced. So is "Poor physical working conditions for FM staff: too low ceiling height, poor daylight conditions, etc." (Table 2, rank 27).

"Unexpected need for double operation due to delay in the construction project" (table 2, rank 31) is another little experienced difficulty.

Within the ten least experienced difficulties 3 are in category 4 (Sustainability), 3 are in category 6 (Others), 2 are in category 3 (O&M of buildings). Only one is in category 2 (O&M of technical installations) and in category 5 (Functionality). None of the least experienced difficulties concern category 1 (Indoor Climate).

The bad and the ugly

The first and third most experienced difficulties concern the quality of documentation and drawings from the construction project (table 2, rank 1 and 3).

"Unexpected high energy consumption due to the lack of commissioning of the technical installations" is the second most experienced difficulty (table 2, rank 2).

Another three of the most experienced difficulties concern indoor climate: too hot, too cold and lack of - or poorly coordinated control - of heating and cooling (table 2, rank 6, 9, 7).

Unexpected operating investments due to the change of costs from Capex to Opex is also high on the list (table 2, rank 5).

Within the ten most often experienced difficulties are 3 in category 1 (indoor climate), 3 are in category 6 (others), 2 are in category 3 (O&M of buildings). Only one is within categories 4 (Sustainability) and 2 (O&M of technical installations). None is in category 5 (Functionality).

Additional difficulties

Respondents were given the opportunity to add difficulties they had experienced, which were not already included in the 35 difficulties identified by us. 8 difficulties were added to the first category, Indoor Climate. They were spread on light, noise, smell, lack of individual control, dry air, and lack of fresh air.

Less difficulties were added to the other categories: 3 to category 2 (O&M of technical installations), 2 were added to category 3 (O&M of buildings). 2 difficulties were added to category 4 (Sustainability), nothing was added to category 5 (Function), and finally 2 difficulties were added to category 6 (Others).

4 DISCUSSION

Documentation from construction projects to FM

The quality of documentation from the construction project was ranked as number 1 and 3, showing that this is highly problematic. In our opinion, this is worrying, as documentation about the building and it's technical installations in many cases is a prerequisite to operate and maintain the new building legally and satisfying. A Norwegian standard has recently been published (Standard Norge, 2018), to aid Norwegian building owners, design teams and facility managers in preventing such difficulties. This could possibly serve as inspiration in other countries, including Denmark, too.

Successful architecture and layout

Due to the limited background questions, we do not know the educational background and experience of the respondents. However, we know from other studies (Kolarik et al., 2017), that facilities managers in Denmark on a managerial level with responsibility for one or more FM disciplines (as the majority of the respondents of our study), are likely to have a technical background. Consequently, there is a possibility, that the respondents having a technical background are more critical regarding technical issues than they are regarding architecture.

Indoor climate

The study shows, that indoor climate is causing FM difficulties. The large research focus on indoor climate further confirms indoor climate to be problematic. Building commissioning is a process, which focuses on the coordinated performance of the building and technical installation throughout a construction project (Mills, 2011). It is gaining momentum in Denmark (Ágústsson & Jensen, 2012), possibly as the result of the many experiences of poor indoor climate in new buildings in Denmark.

Start-up loss

We are surprised to find 'Unexpected high energy consumption due to the lack of commissioning of the technical installations' ranked as number two. The large pool of research concerning the energy performance or reliability gap supports this finding. However, previous research has limited focus on the peak of consumption in the first years of operation. In regard of energy efficient buildings, this frequent experienced 'start-up loss" is possibly overlooked.

5 CONCLUSION

In conclusion, our research demonstrates that facility managers of new buildings experience difficulties in operation due to the legacy from earlier phases of the building's lifecycle. The study was limited to a Danish context, but based on the literature, we have reason to believe, that this is also the case in other countries.

Most experienced difficulty is poor quality of documentation from the project to FM. Difficulties in controlling the indoor climate is another frequent experienced difficulty, resulting in poor indoor environment.

The scientific literature has a large focus on the energy performance gap. In this study, a high number of respondents experienced an unexpected high consumption due to lack of commissioning of technical installation. This poses a problem, as such ‘start-up loss’ have negative impact not only on the economy and occupants, but also on the planet. We recommend both researchers, the industry and policy makers to focus on this loss.

Limitations

We kept the questionnaire short with the aim of an increased number of respondents. However, a limited numbers of questions poses obvious limitations to the study. Omitting 29 completed questionnaires was a result of the lack of background questions. This lead to another limitation of the study, which is the limited number of respondents.

To follow up on some of the unanswered questions derived from this study and to validate the results presented here, we are supplementing the study with in-depth interviews during 2019.

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Appendix 5

Paper E

Tools and methods to establish a feed-forward loop from operation to design of large ships and buildings.

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ABSTRACT

Purpose: This study compares ways to transfer knowledge from the operation stage to the design stage in construction projects of large ships and buildings. Previous studies show that integration of operational knowledge in design of new buildings is important to ensure a high performance of the buildings, though studies show that it is difficult to establish such a feed-forward loop in practise. Comparatively little research has been carried out in knowledge transfer in construction projects of ships.

Methodology: The study was done in three steps. First, five practitioners experienced in ship construction projects, as either ship owners or ship designers, were interviewed to gain insights into the integration of knowledge from the operation stage. Secondly, a literature review was conducted for insight on knowledge transfer in building design. Finally, a workshop with five other practitioners representing both the building industry and the marine industry was held to validate the findings.

Key findings: The analysis identified similarities and differences between the shipping and building industries with respect to knowledge transfer from operation to design. The findings are divided on two aspects: A) General conditions and B) Practical tools and methods. The study furthermore investigated two approaches to knowledge transfer; a technocratic approach and a behavioural approach. The study identified examples of both approaches. Some tools and methods were used by both the shipping and building industries, e.g., project reviews by operational staff and commissioning. Other tools and methods were only used in either building or ship projects and could potentially be adopted by the other type of project.

Impact: The study informs practitioners on ways to establish a feed forward loop from operation to design of either buildings or large ships. Furthermore, the study points at several important aspects of knowledge transfer from operation to design to be further investigated by researchers as well as practitioners.

Keywords: Operational knowledge, building design, ship design, construction projects, knowledge transfer

Rasmussen, H. L. and Jensen P. A. (2018) ‘Tools and methods to establish a feed-forward loop from operation to design of large ships and buildings’, in Proceedings of EFMC in Sofia, Bulgaria, June 2018.

1 INTRODUCTION

The European Commission (2017) has set ambitious goals to reduce energy consumption and greenhouse gas emissions among the member states. Improving new buildings, renovating existing buildings and optimising building operation towards being more sustainable are among the essential measures to achieve such goals (Thuvander et al., 2012).

The operational stage of buildings is by far the most important, when it comes to use of energy and limited resources. In a literature review, Maslesa et al. (2017) concludes the operating energy for non-residential buildings accounts for 80-90% of the total environmental impacts. Decisions made in the design stage have a crucial role on the environmental performance of facilities in operation (Valle Kinloch and Junghans, 2014).

Researchers have identified the design stage as the stage that has the most influence on the future operation of the facility. When the facility is in the operation stage, it is difficult or impossible to change the design to improve the performance (Rasmussen et al., 2017). To consider the operational phase in early design phase, it is necessary to bring in experience and knowledge from facilities already in operation. A feed forward loop needs to be established to ensure that building projects are built by use of experiences from former projects (Jensen, 2009; 2012). However, studies (Jensen and Chatzilazarou, 2017; Rasmussen et al., 2014) show that even experienced building clients with internal operational division struggle with exploiting the knowledge they possess in the new building projects they develop.

Like buildings, ships are large complex physical structures designed and constructed for individual customers. Both types of projects are engaged with large complex physical structures, they are project based, and they go through similar life stages of conception, design, construction and operation. Besides, both type of facility have a long life span, where the operational phase is responsible for the main part of the whole life cycle cost as well as the whole life cycle environmental impact (Knotten et al., 2016).

The difficulties and complexity of knowledge transfer are confirmed by the rapidly growing theoretical field of knowledge transfer (Heisig, 2009). Two approaches to knowledge transfer have been widely discussed: 1) A technocratic approach focusing on knowledge codification and 2) a behavioural approach focusing on the people aspect (Alversson and Kärreman, 2001; Ahmed-Kristensen and Giovanna, 2015). Research within knowledge transfer from operation to design of building projects shows, that the practical tools and methods lacks input from the behavioural approach (Rasmussen et al., 2017).

This study investigates ways to establish a feed forward loop in the design process of buildings ships. The purpose is to bring new insights to research and inform practitioners about tools and methods used in practise to improve knowledge transfer from operation to design.

Two questions guide the investigation:

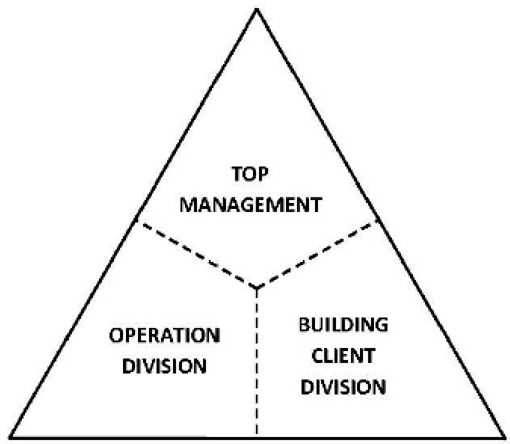
Q1: What are the similarities and differences between the design process of buildings and large ships to establish a feed forward loop from the facility operation to the facility design process?

Q2: Which tools and methods that support a technocratic or a behavioural approach regarding knowledge transfer can be adapted from ship building projects and applied to the design of buildings?

2 THEORETICAL BACKGROUND

Given the opportunity of improving building design though knowledge transfer, researchers have developed lists and categories of the various tools and methods available. For example, Rasmussen et al. (2018) created a list of 42 initiatives a building client can implement to enable transfer knowledge from building operation to building design. This list incorporated the methods for transferring knowledge identified by Jensen (2009; 2012), augmented it with additional tools from a literature review and case study. These were then distributed to a three-partite structure of buildings clients, consisting of Top Management, Building Client Division and the Operation Division, see figure 1 (Rasmussen et al., 2018).

Figure 1: The three-partite building client (Rasmussen et. al., 2018)



Other studies have created different classification systems. For example, Rasmussen et al., (2017) provide a list of "things to do" to transfer knowledge from Facilities Management (FM) to building design differentiated between "tools" and "awareness". Tools are hands-on recommendations such as projects reviews and Life Cycle Costing. Awareness are more diffuse recommendations such as "more attention to FM" and "good communication". Rasmussen et al. (2017) stresses the need for further investigation into the "awareness" aspects of knowledge transfer.

Previous research on knowledge transfer from building operation to building design does not apply much theory from the scientific field of knowledge management, including knowledge transfer (Rasmussen et. al., 2017). This implies a risk that previous research has not fully explored the complexity of the topic in relation to design processes. Similar to the categories of "tools" and "awareness", this study investigates two different approaches to the phenomena of knowledge transfer. On one side a technocratic approach focusing on knowledge codification and on another side a behavioural approach focusing on the people aspect.

Alvesson and Kärremann (2001) distinguish researchers of knowledge transfer (KT) between those who are interested in the 'technological side', and those interested in the 'people side'. They find the latter more widely emphasised in knowledge transfer theory. The opposite is the case, when researchers within FM or construction management investigate KT (Rasmussen et al., 2017). Ringberg and Reihlen (2008) presents a similar distinction, in the field of KT: *"Two major research approaches are dominant in the field, namely positivism and social constructivism" (p. 913).* They advocate for adding a third approach, the socio-cognitive approach, where not only social context and interaction, but also private and cultural mindscapes influence the transfer of knowledge. In contrast, the positivistic approach sees knowledge as 'an objectified asset' (p. 929), which can be directly transferred, for instance, using words.

Recently, some studies have applied knowledge transfer theory to research of construction management. Vianello and Ahmed (2012) investigate knowledge from service to design in the oil industry. Wong, et al. (2008) investigate knowledge transfer from maintenance to airplane engine design. Both studies are heavily based on theory from knowledge management and knowledge transfer. Vianello and Ahmed (2012) make a distinction between a technocratic approach and a behavioural approach in KT, *"The behavioural approach focuses on the behaviour of individuals and on the social relations and cultural factors (…). The technocratic approach focuses on the information systems which are designed to manage knowledge, for instance IT infrastructures, applications, databases and technical procedure"*. Furthermore, the technocratic approach is dominant within the engineering field (Vianello and Ahmed, 2012).

3 METHODOLOGY

A cross-sectional study (Saunders et al., 1997) was employed using expert interviews (ships), literature review (buildings) and a workshop (ships and buildings).

Five interviews were conducted with representatives from the ship design industry between November, 2017 and February, 2018. The same interviewer conducted all interviews, and the interviews were held in the native language (Danish) of both interviewee and interviewer. Citations in this paper were translated by the interviewer.

The interviewees were chosen for their experience in integrating operational knowledge in design, and were been chosen with the purpose of getting the widest possible picture as a maximum variation sampling (Bryman and Bell, 2003). Collectively, the set of interviewees had experience with ferries and other large ships as both clients and designers. Table 1 shows how the experts were divided on branch and working areas. Snowball sampling (Bryman and Bell, 2003) was used. All interviews were held at the interviewees' respective workplaces.

The interviews were in-depth, semi-structured (Bryman and Bell, 2003), and based on a protocol. The interviews had an explorative nature (Saunders et al 1997) and the interview protocol included a list of open questions that the interviewer used as a checklist during the conversation. The interviews were between 34 and 76 minutes in duration (Table 1). All interviews were audio recorded and transcribed. Atlas.ti software was used for coding. Two of the five interviews were conducted, transcribed and coded, before moving on to the following three, allowing for the evaluation of the process and adjustment of the interview guide and the transcription style.

Table 1: Distribution of interviewees and duration of interviews

Role	No.	Interviewee	Interview time
Ship designers	1.	Naval architect, self-employed consultant.	58 min.
	2.	Naval architect, owner of ship design company.	76 min.
Ship owners (building clients)	3.	Former head of new ship division at shipping company. Now head of research centre.	66 min.
	4.	Head of new ship division at shipping company.	57 min.
	5.	Head of new ship division at shipping company.	34 min.

For the matter of building projects, a literature review of previous research on ways to transfer knowledge from operation or FM to design was conducted. Findings of the review along with the researchers' own experiences as practitioners served as basis for comparison.

Preliminary findings were presented and discussed at a workshop held in March, 2018. The validation workshop included five other practitioners: three from the building industry and two from the shipping industry.

A thematic analysis was done (Saunders, 1997) where themes arose from data.

4 FINDINGS

Findings of similarities and differences are divided in to A) General conditions and B) Practical tools and methods. Practical tools and methods includes both examples of a technocratic approach and a behavioural approach to knowledge transfer. The list of tools and methods used only by ships (B2) includes examples, which potentially can be adapted by the building industry. However, the list of general conditions shows that a large number of conditions are similar (A1), but an even larger number are different (A2). For both lists, only a few items are elaborated further in this paper due to word limitations.

4.1 General conditions

General conditions are the conditions related to the context and the specificity of the two industries, for instance in terms of products, competences, markets, technology, regulation etc. Table 2 presents the findings from the interviews for general conditions; distributed on A1) Similarities, and A2) Differences.

Ships are often built in series of e.g. ten identical ships built in a row. Buildings are occasionally built in series, examples are housing complexes with identical units built in a row.

Table 2. General conditions

A1: General conditions, similarities: • The three partite client. • Shared goal and team spirit (between building client and operation) is important. • Challenged by different focal point when design team and operational staff work together. • Limited learning from operation to design within series. • Limited use of IT based tools to store and transfer operational knowledge to design. • The cost of operation stage is by far larger than construction cost.
A2: General conditions, differences: • Overlapping competences in ship design • Naval architects are engineers with a background from technical universities or similar • Building architects are "artists" with an aesthetic focus from academies of fine arts or similar. • Public building clients for large ships are rare • Ships are mobile and built at locations independent on where they are going to be used • New ships are decided with strong business case focus • Ships are in general more alike (more possibility to learn across series) • Different professions do the first design sketches in a new project.

Three-partite client

The three-partite client identified in relation to buildings is also recognized in the ship owner companies. The three parties in ship owner companies, like building owner companies, hold different competences. The new building division primarily employs naval architects and engineers, whereas operation division primarily employs staff with a non-academic background such as navigators and machine engineers. Having in most cases both builders and operators internally, offers a great opportunity to bring knowledge and experience together, described by one interviewee:

"I actually think we are quite privileged here. Where we sit, our operating division is 20 meters away. And we have a morning meeting every day at 9, where we all get up and in just 5 minutes; 'What happened over the night since yesterday?' And if there have been any operating problems on a ship, I always have "big ears." And then I will go ask further (…) and especially, if it is concerning some of the ships I've helped build, that's even more interesting." -Head of new ship division, ship owner.

Shared goal and team spirit

While being co-located has its advantages, the interviewees furthermore emphasize the importance of having a shared goal and team spirit. The interviewees are aware that operational staff and design staff have different foci:

"There are a lot of discussions here when you bring in operational staff… they typically have this perspective that it (the ship) must be reliable... most of them are not much concerned about the overall budgets and the return of investment and profit margins of the company. A captain, who does not arrive at the harbour on time, or a machine engineer, who (…) cannot start an engine, it is so heavily present in an operational division … therefore the focus of their side is very much on reliability, maintenance and safety aspects." -Former head of new ship division, ship owner.

Private versus public clients

With only a few exceptions, large ships are owned by private companies. The opposite is the case for buildings, where many large projects have public clients (e.g., hospitals and university facilities). In contrast to public clients, private clients are not obligated to make national or international tenders. They are free to choose whoever they find most fit for the task, regardless if it is competitive. This can help the private ship owners establish long-term relations with design companies or shipyards. Trust and good experience are mentioned as factors influencing the choice of the design company.

4.2 Tools and methods

The term 'tools and methods' covers specific procedures that are used to support communication, collaboration and decision-making in the design process in the two industries. Table 3 presents B) Tools and methods; distributed on B1) Similarities, B2) Only or mostly used in design of ships, and B3) Only or mostly used in design of buildings

Table 3: Tools and methods

B1: Tools and methods, similarities: • Reviews of the design on different stages by operational staff. • Workshops with different stakeholders, including operational staff, on different stages • Key numbers (measurements) for parts and interior. • Commissioning • Case studies or study trips for stakeholders for inspiration on different aspects of the design. • Total Cost of Ownership/Life Cycle Cost is important, but with short pay-back time
B2: Tools and methods, ships only (mostly) • On-boarding operational staff to the design team. • On-boarding design staff to operation (the design managers board a ship for a week or two) • Captains report. • Survey among operators of ”problematic suppliers” • Extensive model testing during design • Classification (Certification schemes)
B3: Tools and methods, buildings only (mostly) • Environmental Life Cycle Assessment (LCA) • Iterative design process. • 5 year guarantee period

As shown in Table 3, some of the tools and methods are used in both ship and building design process, but some are used differently in the two types of projects.

Commissioning

Commissioning is an example of a method that building projects have adopted from ship building. However, commissioning of ships consists primarily of testing functionality and performance of the new built ship. The commissioning process starts around three months before the shipyard hands over the ship to the owner. In building projects, commissioning – at least ideally - starts already in the early stages by setting up exact and measurable demands. Thus, commissioning serves as an example of the need of transformation if a tool from one sector is transferred to the other.

On-boarding operational staff

On-boarding operational staff to the design team is definitely not a common method in design process of buildings according to the workshop participants from the building sector. In contrast, it is according to the interviewees a very often the case in design process of ships. They are full time employed in the project along with designers and engineers. One of the ship owners gives this description:

“On the project we are doing out in China now, we have hired a machine engineer and a captain from the fleet. They have agreed to approve drawings and discuss with the designers, etc., and in that way, getting their operational experience in to the project. It will typically be a full-time assignment here (...) it's a really good set-up, because they've participated, let's say in the basic design stage and now they're also present at the shipyard. (...) it's not getting any better. (...) they have spent approximately two years (...). Afterwards, they either have to return to the sea or move on to another project.“ -Head of new ship division, ship owner.

On-boarding design staff

On-boarding design staff to operation is the opposite situation. The design manager or part of the design team boards an existing ship of the ship owner typically for a week or two.

"Then there may be a small shipping company down in Italy where you go on board for 14 days or a week on the ship and talk to people on board and that's typically the project manager, the designer who will do the project or the one who is going to write the specification." -Ship designer.

A variant of the on-boarding method is a shorter visit, where design staff study a particular important design issue, described like this:

"*You can take for example the mooring system, which is a very good example, right? The mooring system is important for several reasons (…). So we got into the field and studied, how it was done now. And we had someone taking pictures of it and filmed it, measured the time (…). And then you could show it to some people and do some workshops and like saying ... What's this? What's happening? How can we improve this process?*" -Former head of new ships division, ship owner.

'On-boarding' are rare examples of tools, which draws mostly on the behavioural approach, and are as such interesting to the building sector to notice.

5 DISCUSSION AND CONCLUSION

The analysis identified similarities and differences of knowledge transfer from operation to design in ship projects compared to building projects. The three-partite building client was very similar in the two industries and the need to create shared goals and vision between the design team and the operation team is also recognised in both industries. Commissioning is an example of a tool from ship projects being transferred to building projects, but the need of translating the method or tool to fit the new context became clear.

The participants of the workshop representing the building industry suggested that the financial investment in the design process is possibly larger in ship projects than building projects. Their experiences are that the design process in general is kept at a very low cost. This would obviously be a barrier to adopting the two on-boarding methods. However, Lavikka et al. (2017) provide an example of on-boarding of FM-staff in a building project both during design and construction with a case study of a successful building project of a medical centre in California. They argue that an important reason for the success was that the head of the on-boarded FM staff had experiences from both building projects and building operation. All the interviewees from ships had a background involving both design and operation suggesting a stronger overlapping of competences in ship projects.

At the workshop, it was also suggested that ships are closer to the core business of the ship owners and clients than buildings are for most building owners and clients. This is particularly the case for corporate and public real estate. The similarity to ship owners and clients is probably greater for commercial real estate, where buildings are seen as investment objects.

Technical or behavioural approaches

The study aimed to investigate how the two approaches to knowledge transfer are reflected in tools and methods used in ship projects. In building projects, tools and methods to transfer knowledge from operation to design are strongly influenced by the technical approach, and it was examined if this was also the case for ships. The study does not give a clear answer to this question, although the list of tools and methods clearly includes both a technical and a behavioural approach.

On-boarding of operational staff to the design team is an example of a behavioural approach. Long-term on-boarding allows for establishing a shared goal and team spirit, mentioned as important by the interviewees. This can be challenging in technical-oriented tools like the captains report, where the sending and receiving parties do not necessarily meet face to face. From the interviews it is unclear how the reports are stored, transferred and applied to new building projects.

Research methodology
Neither the list of general conditions nor the list of tools and methods are exhaustive. The interviewer found that it was difficult for the interviewees to describe what they actually did to transfer knowledge, illustrated by this citation:

"Before you came, I thought that I wouldn't be able to say a lot about this subject. I also made a brief brainstorm with my colleagues, and we did not come up with much… but now having talked to you (author comment: for 47 min) it is clear to me, that we actually do a lot. And that we are actually good at it, too…" -Head of new ship division, ship owner.

The expert interviews were effective for outlining and exploring the issue, and provided some insight into the general conditions as well as tools and methods that are used for transferring knowledge in the shipping industry. However, it is difficult to obtain deep insights into knowledge transfer through this method alone. Even if knowledge transfer is something that people do as part of their daily work, their knowledge about it is mostly tacit.

Further research
Further research into knowledge transfer should also incorporate observational data on specific cases, as well as interviews with people while they are working on a specific project. This would supplement and validate the current findings, and would lead to greater robustness in understanding the process of knowledge transfer within the shipping and building industries. It would thereby present even more opportunities for applying general conditions and tools and methods from one industry to the other.

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Appendix 6

Paper F

The challenge of integrating operational knowledge in building and ship design

Rasmussen, Helle Lohmann

Abstract

Purpose. For optimising long-term building operations, building clients need to enable integration of operational knowledge in the design process of new buildings. This study investigates and compares how operational knowledge is integrated into the design of buildings and large ships, focussing on the roles affiliation and the competences of the client's project manager play.

Design/methodology/approach. A cross-sectional qualitative methodology with multiple case studies (five cases) was employed. In addition, 10 expert interviews and 2 validation focus group interviews were conducted. Case studies included in-depth interviews, document analysis and observations.

Findings. The study showed, that organisational affiliation, focus and competences of the client's project management play an important role in how much effort and resources go into ensuring integration of operational knowledge in the design process. In the ship cases, projects managers' highest concerns were operations. Yet, the fewest procedures and tools to integrate operational knowledge in design were found implemented in these cases. Contrastingly, in the building cases, where operations were *not* the main matter of concern of project management, a large number of procedures and tools to integrate operational knowledge in design were implemented.

Originality/value. This research is the first to compare how integration of operational knowledge is taking place in the design process of buildings and large ships and identifying what these industries can learn from each other. Furthermore, it adds to the limited research on operations in large ship design.

Article classification: Research paper

Keywords: Operational knowledge, building operation, knowledge transfer, facilities management (FM), knowledge integration, building design, ship design, matter of concern.

1. Introduction

The increasing focus on optimisation of building operation has highlighted the need for integration of operational knowledge in the design of new facilities (Ganisen *et al*., 2015; Islam *et al*., 2019). Optimisation of building operation potentially leads to reduction in expenses, a reduction in the negative impact on the environment and improved user satisfaction/productivity (Jensen *et al.*, 2018; Fatayer *et al.*, 2019). As, to a large degree, conditions for operations are determined in the design stage of a building's lifecycle (Le and Brønn, 2007; Ganisen *et al*., 2015), considerations regarding operations must be included in the design process (Arditi and Nawakorawit, 1999; Adeyemi *et al.*, 2019; Fatayer *et al.*, 2019; Islam *et al*., 2019; Khalid *et al.*, 2019). Researchers have referred to this as 'feedback' (Way and Bordass, 2005; Le and Brønn, 2007; Hansen *et al*., 2010; Kristiansen, 2010),'feed-forward' (Rasmussen and Jensen, 2018) and 'knowledge transfer' from operations to design (Jensen, 2012; Rasmussen *et al*., 2017; Adeyemi *et al.*, 2019).

Many studies in the literature have adopted the assumption that the more tools and methods are employed to transfer knowledge from operations to design, including operational staff involvement in the design process, the more operationally friendly the building design will be (Jensen, 2012; Rasmussen *et al*., 2019). Studies have identified the building client as the key actor for enabling knowledge transfer (Hansen *et al*., 2010; Jensen, 2012). However, little attention has been given to the fact that building projects are already overloaded with information (Hansen *et al*., 2010; Jensen, 2012; Hall-Adersen, 2013) and the fact that humans have bounded rationality (Simon 1991), thus unable to take all available information into consideration in decision making (Winch, 2010).

In this study, we aim to answer how the competences, affiliation and matter of concern (Latour, 2004; Kreiner, 2010; Brodersen and Pedersen, 2019) of the client's project manager influence the effort to integrate operational knowledge in design. To shed new light on the topic, we have carried out a qualitative study comparing integration of operational knowledge in two similar yet different industries, namely, design of buildings and design of large ships. Thus, we aim to answer what can be learnt about the above-mentioned question by comparing projects of buildings and large ships.

The remaining part of the paper is structured as follows: Section 2 gives a brief introduction to the literature and terminology. The theoretical background for our analysis is introduced in section 3. Section 4 describes the methodology and ends by presenting in brief the five cases. Findings are presented in section 5 and discussed in relation to the literature in section 6. Section 7 concludes the study.

2. Integration of operational knowledge in building design

2.1 Tools and methods

One way of ensuring the presence of operational knowledge in the design process is to involve operational staff (Jensen, 2012). Design review by operational staff and having operations represented in the project steering committee are two examples (Rasmussen *et al.*, 2019). Other tools to ensure that operations are considered in the design process do not necessarily depend on the direct involvement of operational staff (Jensen, 2012; Rasmussen *et al.*, 2019). Lifecycle costing (LCC) is an example of this (Saridaki and Haugbølle, 2019), where the operational expenditure (Opex) is evaluated together with the expenditure of buying or constructing a building part (Capex).

2.2 Barriers

Despite acknowledgement of the importance of considering operations during design by both designers and operational staff (Meng, 2013; Kalantari *et al.*, 2017), studies have identified a low level of engagement of operational staff in the design stage (Hansen *et al*., 2010; Meng, 2013; Fatayer *et al.*, 2019). Reasons for this have been studied, and a large number of barriers have been identified (Hansen *et al*., 2010). Barriers include fundamental characteristics of construction projects: separation of the stages of design and operation, unique projects and changing project teams (Hansen *et al*., 2010; Meng, 2013). Moreover, previous research concludes that building clients and design teams are balancing many interests in the projects besides operational friendliness (Arditi and Nawakorawit, 1999; Lindkvist, 2018; Lindkvist *et al.* 2019).

2.3 Learning from integration of operational knowledge in ship design

Similar characteristics to those described above apply to construction projects of new large ships (Knotten *et al.*, 2016; Gernez, 2019), suggesting that this industry also struggles in linking operation and design. This is to some degree confirmed by the literature (Gernez, 2019); however, literature on this is limited. Studies on the quality assurance concept commissioning demonstrate how a tool that was initially developed and implemented in the shipbuilding industry has successfully been adjusted and applied to the building industry on land (Mills, 2011) with increasing momentum (Ágústsson and Jensen, 2012). Thus, this project set out to investigate and compare how operational knowledge is integrated in the design of large ships and buildings.

2.4 Design processes of buildings and ships

The design process of both buildings and ships consist of a number of sequential stages, with increasing level of details (Gernez, 2019; Mallam *et al.,* 2015; Fronczek-Munter, 2016; Kolltveit and Grønhaug, 2004). In both types of projects, the design process starts with a strategic decision, followed by the development of the building client or ship owner's requirements for the new facility. This is for buildings often called 'brief' whereas it for ships often is called 'specifications'. Level of detail can vary in both industries. Based on the requirements, a concept design (buildings) or a basic design (ships) is developed. Following, a detailed design developed (both buildings and ships) (Fronczek-Munter, 2016; Mallam *et al*., 2015).

Despite obvious similarities in the design process, a previous study comparing design processes of buildings and ships, identifies differences, too (Knotten *et al.,* 2016). In regard of building design, the design team and the construction team are rarely from the same company. In regards of ship design, the design team and the construction team is often from the same company (shipyard). Moreover, new buildings are usually designed entirely from scratch in each project, whereas ship designers often develops a new design based on previous designs. In addition, the study describes, that although both building and ship design processes are iterative, the process of buildings contains more iterations or loops that the design process of ships (Knotten *et al.,* 2016).

2.5 The tripartite building client

The building clients or client representatives have been pointed out as having a leading role in ensuring the integration of operational knowledge in design (Hansen *et al.*, 2010; Jensen, 2012; Meng, 2013). In a study of six public building clients' efforts to integrate operational knowledge in design, the three-partite building client was introduced (Rasmussen *et al.*, 2019). The study concluded that efforts to ensure the integration of operational knowledge in design should be split into the three following parties: Top Management, which decides on and orders new buildings; the Building Client Division, which manages building projects as representatives of the building client; and finally, the Operations Division, which operates the completed building, and thus, holds operational knowledge valuable to the design process (see Figure 1).

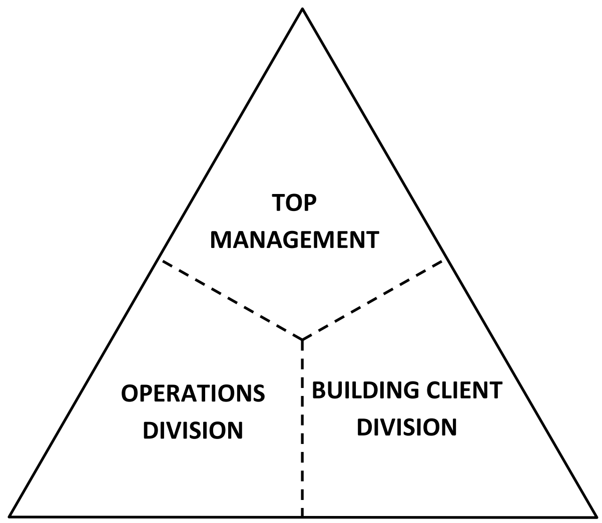

Figure 1: Three-partite building client (Rasmussen et al., 2019)

2.6 Terminology

In this paper, we use the term *project manager* to describe the person who represents the building client or ship owner in the project. The project manager is a person or 'team responsible for ensuring the effective delivery of the project mission for the client' (Winch, 2010, p. 8), holding contracts with consultants, designers and contractors and usually referring to a steering committee and Top Management.

We use the term *design team* to describe the team of professionals who develop and design the new ship or building on different levels of detail, including engineers, architects and interior designers. This is typically, but not necessarily, a temporary team with members affiliated with different companies.

The term *design process* is used to describe the entire process of design, from early planning to detailed design. However, each stage of design has individual characteristics.

We refrain from using the term *facilities management (FM)*, as to our knowledge, it is in limited use and has a slightly different meaning in the ship industry. Moreover, in this study, we investigate a limited part of FM, for which we use the term *operations*. We adopt a definition from research in ship projects proposed by Gernez (2019): '*I define "ship operations" as the assembly of tasks performed by human operators, using the ship systems, in a sequence that enables the delivery of the ship's services'* (p. 88).

3. Theory

3.1 Bounded rationality and the integration of operational knowledge in building design

Much research has been carried out to find answers to how more operational knowledge can be transferred to the design stage of construction projects, based on the assumption that the more knowledge is pushed/pulled (Jensen, 2012), transferred or looped from operations to design, the better. However, the rationality of humans—thereby project managers or designers of building projects—is bounded (Simon, 1991). Thus, they have limited capability for considering all interests and knowledge in decision making, even if the knowledge is present (Winch, 2010). Moreover, construction projects already suffer from 'information overload' (Hansen *et al*., 2010). This challenges the assumption that more knowledge transfer is better and gives more weight not only to how knowledge is transferred but also how project managers and designers deal with this knowledge.

Among many barriers to integrate considerations for operations in design, researchers point to the diversity of interests among the project actors. Thus, as designers have many considerations to balance, operations are not prioritised (Arditi and Nawakorawit, 1999). Following the same line of thought, Elmualim *et al*. (2009) find that actors in construction projects primarily seek to meet their specific needs.

3.2 Matters of concern

A matter of concern (Latour, 2004), in contrast to 'matter of fact', is not solely based on facts but also considers desires (Ripley *et al*., 2009); matters of concern are 'characterized by being rich, complex, surprising and constructed' (Brodersen and Pedersen, 2019, p. 966). A study on matters of concern uses the example of organisational (physical) space to illustrate how space may be a matter of concern to architects but not necessarily to those who work in the space (Kreiner, 2010).

3.3 Knowledge and the model of SECI.

In this paper, we adopt a definition of knowledge as different from information suggested by Nonaka *et al*. (2000): "*Information becomes knowledge when it is interpreted by individuals and given a context and anchored in the beliefs and commitments of individuals"* (p. 7). Thus, knowledge is personal, dynamic, context specific and both—not either—tacit and explicit.

The SECI model, developed by Nonaka *et al*. (2000) is a four-mode model of knowledge conversion and the first of three steps in a knowledge-creating spiral. The four modes are socialisation, externalisation, combination and internalisation. *Socialisation* is sharing of tacit knowledge through shared experience and interaction. *Externalisation* is the conversion of tacit knowledge into explicit knowledge with the aim of forming a basis of new knowledge. *Combination* is gathering and editing explicit knowledge into larger systems of knowledge, thereby creating new knowledge. Finally, *Internalisation* is personalising explicit knowledge into tacit knowledge. The knowledge-creation process is shifting between the four modes in a continuous spiral movement (Nonaka *et al*., 2000). In this study, we discuss our findings in relation to externalisation and internalisation.

4. Methodology

We carried out the study over a two-year period, where we examined and compared the integration of operational knowledge in the design process of large ships and buildings. The study was inductive and done sequentially in three main parts, allowing method triangulation (Yin, 2014), in which findings from the first part led to the design of the second part (Saunders *et al*., 2016). The first part consisted of 10 expert interviews (Meng and Harshaw, 2013). One of the conclusions from the expert interview study, which has already been published, was that although integration of operational knowledge was a part of the daily work life of the interviewees, their knowledge about it was mostly tacit (Anonymous, 2018), and thus, difficult to gain insight into via interviews. Consequently, the second part of our research was a multiple case study, where in-depth interviews were supplemented with archival material, and in one case, observations, to allow data triangulation (Yin, 2014). Furthermore, the case study method gave us the opportunity to discuss concrete actions and conditions in specific projects with the interviewees, making the concept of knowledge integration less abstract.

Finally, as the third part, we held two focus group interviews to validate our findings. One interview, with two interviewees experienced in ship design and operation, focussed exclusively on findings from the three ship cases. The other focussed on findings from both ship and building cases with interviewees who had experience in projects of either ships or buildings. Some interviewees were interviewed more than once in the case study, but there was no overlap between interviewees for the expert, case study and validation interviews.

4.1 Expert interviews

This part of the study was partly described in two earlier publications (Anonymous 2018; 2019) and will only briefly be described here. We conducted 10 face-to-face, semi-structured interviews (Saunders *et al*., 2016). We selected interviewees for their experience in integrating operational knowledge in design of either ship or building projects. Due to the researchers' prior knowledge on building projects, more interviews were held with experts of ship projects (six interviews) than with experts of building projects (four interviews). The interviews were explorative and lasted 30–80 minutes. Audio recordings of the interviews were transcribed and then coded using Atlas.ti with a combination of predefined and emerged codes (Nardelli and Rajala, 2018).

4.2 Multiple case study

In this study, we define a case as the design process of a new ship or building. Furthermore, we delimit the study to focus on general conditions of the projects and efforts, including tools and methods, to consider operation in the design process.

Our case selection strategy was based on findings from the expert interviews. First, we selected ferries over cargo ships to increase the similarities to buildings, easing the comparison. Moreover, we selected cases with high ambitions for energy efficiency, as we assumed this was a driver for integrating operational knowledge in the design process, thus selecting 'best cases' (Yin, 2014). Further, again based on findings from the expert interviews, we selected cases with different general conditions, for example public or private clients, predicting contrasting findings (Yin, 2014). Due to constraints on time and resources, we selected medium-sized cases with client organisations based in Denmark. Since the duration of the study did not allow a longitudinal study, we selected cases at different levels of completion (design, construction, operation).

The selection of cases followed an emergent research design (Yin, 2014), allowing us to respond to anomalies and preliminary findings by adjusting the design on the way. An example of this is that, based on preliminary findings from the first cases we conducted, we realised that it possibly makes a difference whether the new ship or building is designed to be part of a portfolio or a 'standalone' facility. The two ship cases we had selected at this time were both standalone facilities (cases 1 and 2), and the two building cases were part of a portfolio of facilities (cases 4 and 5). Consequently, we added a third ship case, which was a part of a portfolio of ships (case 3). Due to time constraints, we had to limit the data collection for case 2 to make time to collect data for case 3, for which data collection was also limited.

Fourteen semi-structured interviews were conducted as part of the case study, including 11 individual and three focus group interviews. The interviews were done face-to-face except for three individual interviews done by Skype or phone due to geographical distances. All interviews in this study were in Danish. Citations are translated to English by the author.

A cross-case synthesis was applied for analysing the data (Yin, 2014). In principle, we treated each case individually, developing individual case reports. The content of the case reports followed a list of themes from the expert interviews, which we supplemented with emergent themes (see Table 1). When possible, we applied data triangulation to describe the theme. To validate the individual reports we sent the reports to the respective interviewees. This resulted in minor corrections of the individual reports in all five cases. Finally, we analysed all case reports for similarities and differences across them. We supplemented the findings with the results from the expert interviews (first part of the study). Moreover, we discussed our findings in the validation focus group interviews (third part of the study) and included their comments in the findings presented in this paper.

Table 1: Themes investigated and described for each case

Themes investigated and described individually for each case
Project background/need
Building client/owner organisation
Public/private client/owner
Project organisation, including project manager's education and experience
Consultants and design team
Timeline
Change of key staff during design stage
Tender strategy
Handling of changes in design and construction
Involvement of operational staff in the design process
List of implemented tools and methods to integrate operational knowledge in design
Description of the use of each implemented tool or method
Capex and Opex
Criteria for success
Critical incidents leading to changes in design crucial to operation
Energy efficiency
Unique design or part of series (or larger project)

4.3 Case presentation

Table 2 shows basic information on the five cases. An additional brief presentation of the cases is provided below.

Table 2: Basic information on the five cases

Industry	***Ships***			***Buildings***	
Case	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**
Project	Passenger and car ferry	Passenger and car ferry	Passenger and car ferry	Airport extension	Hospital building
Client	Private	Public	Private	Private	Public
Budget (Capex)	8.5 million Euros	36.2 million Euros	67 million Euros	60 million Euros	80.5 million Euros
Standalone facility or part of portfolio	Single	Single	Portfolio	Portfolio	Portfolio
Stage when studied	Construction	Design	Operation	Operation	Design
Data collection	4 Interviews Documents	2 Interviews Documents	1 Interview Documents	4 Interviews Documents	3 Interviews Documents Observations

Case 1 concerned the design process of a small privately owned passenger and car ferry, connecting two small Danish Islands, with one connected to the mainland by a bridge. A local group of citizens of one of the harbour cities, who were dissatisfied with the municipality closing down the municipal ferry route, initiated the ferry. They founded a limited company with the only purpose of buying and owning the new ferry, and they funded the ferry by the sale of shares to private individuals and the raising of loans. The ferry is 50 m long and has the capacity for 32 cars. It is a hybrid ferry sailing partly on batteries and partly on diesel. The batteries are recharged in port and primarily replace diesel when entering and exiting the two ports. The ferry is expected to be in operation by the end of 2019.

Case 2 related to the design process of a middle-sized public-owned passenger and car ferry connecting a small Danish Island with the mainland. The new ferry is replacing two small old ferries with the main purpose of increasing capacity. The new ferry is 112 m long and has a capacity of 188 cars and 600–750 passengers. The planning and design process has been far from linear, partly due to political disagreement, and in fall 2019, the ferry was in the process of design without having contracted a shipyard. Like in case 1, this ferry was designed to be a hybrid ferry sailing partly on batteries and partly on diesel.

Case 3 concerned the design process a large private owned passenger and car ferry. It connects two parts of Denmark, creating a shortcut across Denmark for many travellers. It is a high-speed catamaran ferry, supplementing the ship owner’s other ferries operating the route. It has a capacity of 450 cars and 1000 passengers. It is 109 m long and 30 m wide. The ship owner calls the ferry a ‘super ferry’ because of its high speed, high capacity and low energy consumption. The ferry has been operating since spring 2019, and the ship owner is a large Danish ferry operator with routes several places in Denmark.

Case 4 concerned the design process a privately owned commercial extension of an existing airport building in Denmark. An increasing number of passengers is the main reason for the extension. Functions include a shopping area, flow space, storage and offices. The size of the extension is 9000 m^2.

In addition, space in the existing airport buildings were included in the project, adding up to 12.000 m^2. The handover from construction to operation took place shortly prior to data collection.

Case 5 concerned the design process a new public hospital building connected to a larger—also new—hospital project in Denmark. The building client is the region (public), however a privately owned foundation funded the project with the aim of strengthening treatment and research of a specific disease by establishing a united centre. The case building is 12 000 m^2. As the project is a part of a larger ongoing building project, it shares some resources; however, it has an individual organisation with project management and design team. Data collection took place when the project was in the design stage.

5. Findings

5.1 Affiliation of project management in regard to the three-partite building client

In all five cases, project management was affiliated with the client company. In two cases, project management was divided between more than one person (cases 1 and 5). The building client of both building cases (cases 4 and 5) had a three-partite building client organisation consisting of a Top Management, Operations Division and Project Management Division. In both of these cases (cases 4 and 5) project management was affiliated with the Project Management Division, specialised in managing new building projects. In contrast, none of clients of the three ship cases (cases 1, 2 and 3) had a Building Client Division, although one had purchased several new ferries of considerable size in recent years (case 3). Consequently, project management was affiliated with either Top Management (cases 1 and 2) or Operations Division (case 3). Figure 2 illustrates the distribution of project managers.

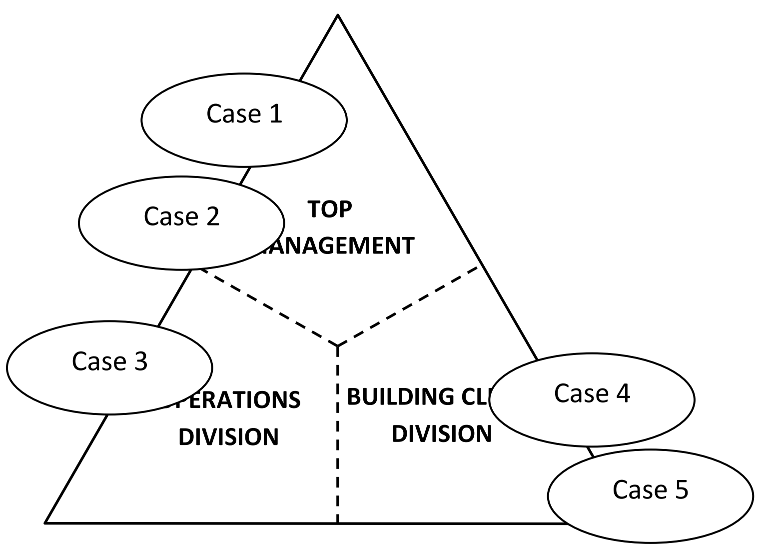

Figure 2: Affiliation of project management in the five cases

The project manager of case 3 describes the advantages and disadvantages of managing large projects in the Operations Division as follows:

> *"We don't have a project division. All of a sudden, we get these huge projects, which we as an Operations Division must manage with operations staff. It is a huge challenge! We might have neglected operations a bit (…). [Being affiliated with the Operations Division] is exactly the reason why we have "our finger on the pulse". I receive information on a daily basis about problems on our ferries (…). I can bring this information directly into the project, saying: Did we remember this or that?"* (Project manager of case 3).

In contrast to the three investigated ship cases, the interviewed experts from shipbuilding provided plenty of examples of ship owners having a three-partite building client organisation. The experts generally used the term 'new building division'. The interviewees in the ship validation interview further confirmed the contradiction between the three investigated cases and other cases of which they were aware. They suggested that this was due to the ship owners' (of the cases) limited purchase of new ships or simply because the organisations were rather small in size. However, they pointed out that even large ship owners have changed between having an individual new building division and not having one over time. Regarding building clients, the interviewees of the building validation interview reached the same conclusion: Not all building clients have a Building Client Division; it depends on their project portfolio and the organisation.

5.2 Project management competences and matters of concern

The competences and experience of the project managers of the cases were aligned with their affiliation in their organisations. Thus, the project managers of the building cases (cases 4 and 5) had strong competences in project management. Managing and completing projects was their matter of concern, whereas Operations or Top Management was not. In contrast, the project manager's matter of concern of one ship case (case 3) was operations as he was the deputy director of the Operations Division. He had strong skills in operations and maintenance (O&M), including highly technical skills. In the other ship cases (cases 1 and 2), project management was part of the Top Management. Thus, their matter of concern was 'the business' of the new ship, including keeping the ship sailing and bringing in money throughout the ship's lifetime. The following quotation is the project manager of case 3's description of the criteria of success, illustrating his broad and long-term focus of the project:

> *"It would be a disaster if we put a new ferry into operation and it turned out to consume more fuel than the ships we already have. It must consume less fuel! In addition, it must be good for the crew, meaning that the ship must be operational (and) enough space for the operations workflows is needed. And customers should of course be happy with the ship, right? The ship must be pleasant to be on, and most importantly: It needs to sail! It must depart on time! (…) Every time a ferry misses a departure, we lose income up front, but moreover, we can see that even when the ferry sails on time again, the customer does not immediately return. It takes a month or so before the customer is back."* (Project manager and deputy of O&M, case 3).

5.3 Use of tools and methods to integrate operational knowledge in the cases

Analysis across the five cases showed that the fewest tools and concepts to ensure operational considerations during the design process were implemented in ship case 1 and 3. Most tools and concepts were implemented in the two building cases (cases 4 and 5). At first sight, case 2 was an exception from the two other ship cases, as the same high number of tools were implemented as in the building cases. However, by further mapping the use of the tools, we found that the project manager had implemented 'lighter' versions of the tools than in the two building cases (cases 4 and 5). In section 5.5, 'Design review by operational staff' serves as an example of the very different use of the same tool. In the following section, the implementation of LCC is described. Table 3 shows whether the project manager implemented few or many tools to integrate operational knowledge and whether the project manager or design team worked with operational budgets at a business case level and or at a design level, see also section 5.6.

Table 3: Tools implemented in the cases

Industry	***Ships***			***Buildings***	
Case	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**
Stage when studied	Construction	Design	Operation	Operation	Design
Affiliation of project manager(s)	Top Management	Top Management	Operations Division	Building Client Division	Building Client Division
Implemented tools	Few	Many tools, light	Few	Many tools, heavy	Many tools, heavy
Opex in business case	Yes	Yes	Yes	Yes	Yes
Opex in design	Yes	Yes	Yes	No	No

5.4 Operating budgets during planning and design and LCC

We identified operation budgets at two different levels of detail in the cases. The first is what we call the operation budget at the business case level. At this level, operation expenses are roughly estimated to help decision makers decide whether to approve the project. In all five cases, the interviewees described that such initial considerations on operation expenses had been done. However, this type of initial budgeting of operation costs was not based on the actual design.

We call the second type of operation budgets 'design-specific operation budgets'. In this type of budget, expenses are based on the actual design, and they are continuously updated when the design is further detailed or changed. In all three ship cases (cases 1, 2 and 3), we found that the project managers worked with 'design-specific operation budgets' during the design, typically for 1–5 years from handover. We had the opportunity to look at the operation budget of case 1. It included operational expenses on fuel, cleaning, staff salary and maintenance. Expenses related to Top Management were included, for example, expenses related to loans and insurance. Furthermore, the budget included estimated income, comprising the expected number of cars and passengers and governmental financial support.

Moreover, interviewees from the ship cases provided examples on how they considered both Capex and Opex when evaluating specific parts of the design, which we find is equivalent to LCC. Interviewees of case 1 mentioned the layout of safety equipment as an example because the layout effects the legally required minimum staff on board. Thus, different layouts resulted in differences in staff expenses during operations.

The project manager of case 3 gave another example:

> *"For us, when we buy engines, there are three things that are really important: (First, there is) the purchase price of the engines (…). Then there are spare parts and the cost of maintenance. And finally, there's the reliability of it. Do things keep running, and can you fix them overnight? (…). Sellers, they often think that the purchase price is the only important issue."* (Project manager, case 3)

In contrast, we found no design-specific operation budgets in either of the building cases (cases 4 and 5). Correspondingly, interviewees from building cases 4 and 5 did not report that they had implemented LCC or similar, even though it in Denmark is mandatory for public clients on large buildings projects. However, in case 4, the project management argued that, to a large degree, they had based the design on the design guidelines developed by the building owner, and they expected LCC to have been a part of developing the guidelines. This is possibly also the situation in case 5, which was a public client, although the interviewees did not mention it. Table 3 indicates whether operation budgets was included in the business case of the five cases. Moreover, table 3 indicates whether detailed operation budgets were developed and maintained in the design process of the five cases.

5.5 Design review by operational staff: A tool and a process

The project managers of all five cases had implemented the tool 'design review by operational staff'. However, we found five very different versions of the tool as illustrated in Table 4.

Table 4: Design review by operational staff

Case	**Stage when studied**	**Action**	**Operation reviewers**	**Type of interaction (primary)**	**Type of review (primary)**
1	Construction	Part of meetings with management company	External	Face to face	'Instant' review
2	Design	Drop-by meeting—once Technical director in steering committee	Internal	Face to face	'Instant' review

3	Operation	Parts of design sent to specific members of staff once Technical director is project manager	Internal	E-mail	Desk work, individually
4	Operation	'Review project' Stage gate reviews: Complete project material and review templates sent to reviewers Additional review on parts of design (by e-mail)	Internal	Spreadsheets	Desk work, individually
5	Design	'Review project' (external facilitator) Facilitating review meetings on specific parts of the design Continuous review by on-boarded operational staff to design team Final review of complete project material	Internal	Face to face	'Instant' review

The project management of case 1 did not have an internal Operation Division to review the design. Instead, they asked an experienced ferry management company to give advice on the design while discussing a future management agreement. Among other things, the external management representatives suggested that the manned cafe should be replaced with vending machines. Following this, the project managers asked the design team to change the design accordingly. Thus, a small effort in a meeting led to a big change in the design and the future operation of the ferry.

In case 2, project management called for a drop-by meeting with all staff who were interested. The interviewee described it as follows:

> *"It was a joint meeting on board one of our ferries, where all staff members were invited to simply come during a break, while both ferries were in port. (…) I said welcome and the consultants [designers] gave a presentation of it [the design proposal]: what the design currently looked like. They had put out drawings on some big tables. Then they walked around talking to the staff and the staff could point and say, 'wouldn't it be better if this and that' (…). The consultants noted them [the comments]. (...) Some comments made good sense, and some did not. Some even made good sense but were not incorporated in the design because something else was considered more important."* (Project Manager, case 2)

In addition, the technical director of case 2 was part of the steering committee, and thus, was possibly continuously reviewing the project together with the rest of the committee.

The project manager of case 3 invited a few relevant staff members to review only a part of the design. As an example, he mentioned that he asked a captain to review the bridge design. He sent drawings and a call for comments on email, and he added in the interview that he regretted not organising the reviews better. He suggested that the project manager should print all drawings and ask relevant staff to pick up a copy followed by a face-to-face meeting to discuss the design.

The design review by the operational staff of case 4 was a project in itself, with an independent time schedule and organisation. It followed a described procedure, including 'desk reviews' by operational staff at each project stage, and followed a predefined schedule. The review process was considered a part of building commissioning, and the commissioning leader acted as a 'single point of contact' between Operations Division, the Building Client Division and the design team. The reviews were not done directly by operational staff, but instead, by so-called asset managers, who were representatives of the Operations Division, each responsible for specific 'assets' like Fire and Safety equipment, Building Management Systems, HVAC and so on. The commissioning leader distributed the design material, drawings and specifications digitally to the asset managers. They reviewed the project material, filled in their comments in a spreadsheet template and returned it to the commissioning leader. He gathered reviews from the asset managers and forwarded them to the project manager, who again forwarded them to the design team.

The asset manager responsible for Fire and Safety was interviewed as part of this study. She described the review as time consuming, estimating that she spends between 8 and 15 hours reviewing a case like this. When reviewing, she draws partly on her experiences from operations, as well as largely on her previous experience as a consultant. She had developed a 'checklist' based on experience of 'what usually goes wrong in the projects', but she received no formal or informal instructions on what and how she is expected to review the material.

Analysis of the review comments (spreadsheets) showed that many review comments had more to do with the quality of the project material and less to do with operational knowledge. We asked the asset manager if that was her interpretation, too. She answered:

> *"To a high degree! I get really disappointed on behalf of the design industry, when sometimes our reviews have the characteristic of being a quality check of their work (…). When I have to read things through, I get annoyed to find errors that should have been discovered before I got the material. And yes, it is time consuming for me to sit down and comment on something that should be found already."* (Asset manager, case 4)

In cases where review comments need to be further discussed or if a certain part of the design solution needs to be discussed ad hoc, the asset manager and relevant members of the design team meet face-to-face, communicate by phone or reach out by e-mail. They then have a forth-and-back discussion that we think is best described as a negotiation. The project management has a defined procedure to handle issues where Asset Managers and design team members do not reach an agreement.

As in case 4, the review in case 5 was a 'project within the project', with an individual organisation and time schedule. The project management had hired an external consultant to facilitate the review process, which included three face-to-face meetings with representatives from operations, the design team and project management. The first of three meetings was observed as part of this study. The purpose of the observed meeting was to elicit the operational staff's comments on specific parts of the design proposal. As an example, two architects presented the design of a central staircase orally while pointing at large, printed floorplans laid out on the table. The operation staff immediately approved some parts of the design solution, rejected others and still others started what we think is best described as negotiation. As part of a discussion on textiles, the design team and project manager asked the operational staff if they could look into types of textiles they would find appropriate. The operational staff answered that they were too busy to do so, and furthermore, they thought this was part of the design task. The design team and facilitator took notes, while the operating representatives did not write anything down. The facilitator distributed minutes from the meetings afterwards. In addition to the three pre-scheduled review meetings, to a large degree, ad hoc reviews took place as some members of the operations staff were physically moved to the design team's office part time.

To sum up, we found that the tool 'design review by operational staff' was implemented very differently in the five cases. In case 1-3, the ship cases, the review did not take up many resources or efforts. Yet, the project management appeared to have a high degree of considerations for operations in the design process. In cases 4 and 5, the building cases, design review by operational staff is best described as a project in itself, rather than as a tool. The review process was in both cases resource intensive, and led to changes in the design. However, analysis of reviewer comments, interviews and observations revealed that part of the review could be characterised as quality check of the work of the design team. The review by operational staff was in some cases highly depended on written communication (cases 3 and 4) and in other cases based on face-to-face meetings (cases 1, 2 and 5). Thus, whether the review was mostly written or oral did not correspond to whether the case was a ship (cases 1, 2 and 3) or a building (cases 4 and 5).

6. Discussion

6.1 The paradox between the project manager's matter of concern and the use of tools

In the two building cases (cases 4 and 5), operations was not the matter of concern for the project managers. However, these project managers implemented more tools and methods to integrate operational knowledge in design than those in the ship cases (cases 1, 2 and 3). In contrast, the project manager of case 3, one of the two cases with the fewest tools and methods, was the deputy manager of O&M; thus, operations was his matter of concern. At first glance, this is a contradiction: The project managers with the lowest interest in operations use more tools and spend more time on the project to ensure that operations staff are involved in the design projects. Contrarily, project managers with the highest interest in operations use fewer tools and spend less time involving operations staff. However, referring to the SECI model of knowledge conversion, project managers with knowledge and experience in operations have already embodied and internalised the operational knowledge (Nonaka *et al.*, 2000). Furthermore, as it is their matter of concern, even with bounded rationality, we assume that they will consider operations throughout the design process intuitively.

Contrastingly, in the cases where operations were not the matter of concern of project management, deliberate and almost endless efforts to enable operational considerations in the design process were needed. Project managers were depending on externalisation of knowledge from operational staff. However, given their bounded rationality (Simon, 1991), together with the overflow of information in design processes (Hansen *et al*., 2010), there was a risk that they would make decisions in the design process in accordance with their matter of concern, regardless of whether it made operations difficult or increased Opex.

Especially in one of the building cases, the involvement of operational staff was heavily based on written communication, resulting in a vast amount of explicit information (spreadsheets), which was transferred to the project team. This implies a risk of information overload (Hansen *et al*., 2010). In the SECI model (Nonaka *et al.* 2000), turning explicit knowledge into explicit is the second mode, externalisation. The interviewees of this case mentioned a few initiatives to 'socialise' with the aim of achieving shared experiences and interaction between operational staff and the project team. However, it remains an unanswered question, whether the actors managed to move between the four modes in the SECI model, in order to convert the explicit knowledge into new knowledge, which enabled the project team to take operations into consideration in the design process.

6.2 It is not about whether tools are used but how they are used.

Our analysis of the 'design review by operational staff' tool showed, that project managers interpreted and implemented this tool in distinct ways. This makes surveys on the use of the tool, and possibly other tools to integrate operational knowledge (Rasmussen *et al.*, 2019), problematic. The interesting thing to investigate is not *whether* the tool is used, but rather, *how* it is used, particularly whether a tool or a process are implemented in a way that enables a process of knowledge conversion (Nonaka *et al.* 2000). Thus, this study question the underlying assumption in previous research, that the more operational staff is involved in design processes, the more operational friendly the design will be (Jensen, 2012; Rasmussen *et al*., 2019).

6.3 Does extensive use of tools and involvement of operational staff decrease project management and design teams' effort in terms of operational considerations?

Concerning the design team's effort and initiative to take operations into consideration in the design process, we found that, in the building cases where operation was not the project managers' matter of concern, the project managers and design teams were depended on the operational staff to supply operational knowledge in the project. In case 4, the asset manager clearly expressed her opinion in the interviews that a large part of her comments in the design review should have been taken care of by the design team. In case 5, the design team and project manager tried to convince the operational staff to investigate types of textiles they could use in their design. We see this as an indication of a negative spiral, where increasing efforts are needed to support operational considerations if operations do not represent the matter of concern of the project manager and possibly the design team. More research is needed to determine whether extensive operational staff involvement leads to a decreased effort to consider operations in the design by the design team and whether this is problematic.

6.4 What building clients can (not) learn from ship owners relating to the project manager's role in the integration of operational knowledge in design process?

Looking at the ship cases in our study, together with recommendations from previous studies (Mohammed and Hassanain, 2010), it may seem tempting to recommend that skilled project managers whose matter of concern is to complete the project are replaced with operational staff with an operational matter of concern. However, this could lead to neglect of other important parameters in building projects.

6.5 What ship owners can learn from building clients about the project manager's role in operational considerations during design?

In line with the literature, we found that project managers are balancing many parameters in both ship and building projects. Having operations as the matter of concern of the project managers of the ship cases may cause other important aspects to be neglected. First, the management of the project is possibly less efficient if the project manager lack skills in that regard. Moreover, in the ship cases, we found little consideration of user experience. A validation focus group interviewee commented on this finding, stating that it was not representative; the interviewee knew examples of ship owners, who were highly occupied with user experience as they consider it is an important competition parameter, when it comes to passenger ferries.

6.6 Similarities—cases are not representative

From the expert interviews and validation focus group interviews, we found examples of, on the one hand, building projects managed by operational staff, and on the other, ship projects managed by skilled project managers. Such projects were not included in our case study. Consequently, we are not able to tell whether our findings were related to the cases' involvement of either ships or buildings or if they related to the affiliation and matter of concern of the project manager, regardless of whether the project concerned a ship or building. Our validation interviewees thought the latter was most likely the case.

The five cases were not equally complex. Both the organisation of the project, e.g. number of stakeholders, and the fact that the project needed to fit into either an existing portfolio (case 4) or larger project (case 5) made the building cases more complex than the ship cases. Even the third ship case, which was added to the study during data collection to match the building cases in regard of size and portfolio, did not match the building cases in regard of complexity. This is in line with previous research comparing ship and building design processes (Knotten 2016). More studies are needed to answer, whether operational considerations are more effortless in building projects with low complexity, and oppositely, whether operational considerations take up extensive resources in ship projects with high complexity.

In regard of buildings, this study shows an extensive involvement of operational staff in the design process of two specific cases. This is unlikely to be generalizable, as we selected cases to be 'best cases' (Yin, 2014). Nevertheless, it contradicts previous research concluding that operational staff is limited involved in the building design process (Hansen *et al*., 2010; Meng, 2013; Fatayer *et al.*, 2019). Thus, this study contributes to a nuanced description of the level of operational staff involvement in new design processes.

6.7 The sidecar metaphor from occupational health and safety management (OHSM)

Researchers on OHSM have introduced the sidecar metaphor to illustrate that they found safety organisations marginalised in relation to the general decision-making processes in companies (Frick *et al.*, 2000; Jensen, 2002). Although systematic work on health and safety was done in companies, health and safety issues were handled in separate organisations and remained an unimportant aspect of decision making (Dul and Neumann, 2009), as a sidecar to the main vehicle. Similarly, in the field of ergonomics, researchers found that ergonomists are struggling to find a strong voice in design projects. They recommend that ergonomists involved in building projects emphasise how their involvement in the design process helps project managers reach their project success factors (Dul and Neumann, 2009). As such, it is recommended that ergonomists should tap directly into the matter of concern of project managers. A similar recommendation is possibly applicable for the involvement of operational staff in design projects in cases where operations is not the project manager's matter of concern.

Other researchers are suggesting participatory design methods when ergonomists are involved in the design process (Broberg *et al.*, 2011; Conceição and Broberg, 2018). We suggest that practitioners and researchers should investigate whether such methods could be useful when involving operational staff in design processes, with the aim of establishing a co-creating process (Nardelli and Broumels, 2018).

6.8 Implications for research and practise

The findings of this study imply the need for researchers to have a much stronger focus on finding recommendations on how building clients or ship owners motivate project managers to take operation into consideration, without jeopardizing other important issues as e.g. end-user experience. This study finds that bringing operation into the matter of concern of project managers is a strong motivation factor. We hope that future research will investigate possible ways to do so.

For practitioners, the findings of this study has implications in relation to how operation is taken into consideration in design processes. For ship owners, the study showed that their project managers already to a high degree ensured that operation was considered in the design process, even with few resources spent. However, ship owners could possibly benefit from ensuring that other issues as e.g. user experience and aesthetics are taken into considerations, too, as we believe such matters will play an important role for ferry passengers in the future.

For building owners, the findings of this study imply a need to evaluate the processes implemented to ensure operational considerations in the project. First, building owners need to evaluate, whether the operational staff is taken over tasks from the design team. If they are, then it must be evaluated, if they are the best to fulfil design tasks. Secondly, findings of this study indicate that project managers ensure that operation is considered more efficiently, if operations are a part of the project managers' matter of concern. Hence, based on this study, building owners are recommended to find ways to make operation a matter of concern for project managers and possibly design team staff, too. We suggest that building owners can be inspired by the way end-users are involved in design processes (Brodersen and Lindegaard, 2016; Broberg *et al.*, 2011; Conceição and Broberg, 2018) to test, if a similar approach is fruitful when involving operational staff.

7. Conclusion

In this study, the project managers of the ship cases had long-term interests in the new facility, were focussed on operation and were broadly skilled in the operation stage of ships. In other words, operations represented their matter of concern. Yet, they spent only limited resources on ensuring that operations was considered during the design. Contrastingly, the project managers of the investigated building cases had a short-term interest in the facility before moving on to the next; their focus was on completing the project, and they were skilled in building projects and not operations. Their matter of concern was managing the project, not operations. Yet, they spent extensive project resources ensuring operational knowledge in the project.

Despite the great effort to integrate operational knowledge, we conclude that operations is not the matter of concern of the clients' project managers for the building projects. Project managers' compensate for this by implementing a large number of tools and methods to integrate operational knowledge in the design process. However, the findings showed that a lack of operational considerations remains when design solutions are selected; as an example, LCC was not implemented in either of the two building cases. Based on this, we recommend research and practice focusing less on developing additional tools and the barriers to implement them and more on how to deal with the finding that operations is not the matter of concern of project managers of building projects.

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Appendix 7

List of other publications

List of other publications

Publications apart from the papers included in this thesis are listed below [English translation of Danish titles in brackets].

Conference paper/abstract

Rasmussen, H. L., Jensen P. A. and Gregg J. S. (2017) 'Transferring Knowledge from Building Operation to Design—A Literature Review', in *Proceedings of the IRWAS 2017 Conference*, Salford, UK, 11–12 September 2017.

Conference abstract: Rasmussen, H. L. (2019) 'Comparison of user involvement and operational staff involvement in the design process of a hospital building project', in *Book of Abstracts of the Cirré Conference 2019.*

Book chapters

Rasmussen, H. L. (2019) 'Integrating operational knowledge in design', in Jensen, P. A. (ed.), *Facilities Management Models, Methods and Tools*. Routledge. pp.245-251.

Rasmussen, H. L. (2018) 'Integrering af driftsviden i design [Integrating operational knowledge in design]', in Jensen, P. A. (ed), *CFM forskning igennem 10 år—De vigtigste modeller, metoder og værktøjer* [CFM research in ten years—The most important models, methods and tools]. Lyngby, DK: Polyteknisk Forlag.

Rasmussen H. L., Nielsen C. N. and Nielsen S. B. (2018) 'Facilities Management', in Jakobsen A. and Kolarik J. (eds), *Energirigtig drift af det rette indeklima* [Energy efficient operation of the right indoor climate]. The Copenhagen School of Marine Engineering and Technology Management.

Rasmussen, H. L. (forthcoming) 'Bird and suitcase', in Kirkeby, A. M. and Sigbrand, L. (eds), *Antologi: Byg bro mellem byggeriets parter* [Anthology: Bridge the actors of the building industry]. Denmark: Danish Building Research Institute, Aalborg University.

Reports

Kolarik, J., Harbo, J. S., Nielsen, S. B. and Rasmussen, H. L. (2018) *Frederiksberg-undersøgelse: Kortlægning af driftspersonalets færdigheder, kompetencer, praksis og hverdagsudfordringer med hensyn til indeklima og energi* [The Frederiksberg study: Mapping of operational staff's skills, competences, practices and every day challenges regarding indoor climate and energy]. ELFORSK.

Non-scientific publications

Rasmussen, H. L. and Due, P. H. (2019) *FM-vanskeligheder i nybyggeri – fra tro til viden*. [FM difficulties in new buildings – from rumours to facts] FM Update June 2019 (Quarterly magazine of the Danish Facilities Management Network).

Rasmussen, H. L. and Due, P.H. (2019) *FM-vanskeligheder i nybyggeri*. [FM difficulties in new buildings] Maskinmesteren, June 2019 (Monthly magazine of the Danish Marine Engineering Association).

Rasmussen, H. L. (2018) *Bird or suitcase? Two ways of transferring your FM knowledge*. eFMi 46, October 2018 (Quarterly digital magazine of the European FM Association).

Rasmussen, H. L. and Nielsen, S. B. (2018) *Indtryk fra den europæiske FM konference* [Impressions from the European FM conference]. FM Update, vol. 3, 2018 (Quarterly magazine of the Danish Facilities Management Network).

Rasmussen, H. L. (2018) *Flytter du din FM viden med fugl eller kuffert?* [Are you transferring your FM knowledge by bird or suitcase?]. FM Update, vol. 2, 2018 (Quarterly magazine of the Danish Facilities Management Network).

Rasmussen H. L., Nielsen S. B. and Møller A. B. (2017) *JA! til driftsvenligt byggeri på DTU—men hvordan i praksis?* [DTU says yes to operational friendly building but how should it be done in practice?]. Maskinmesteren, January 2017 (Monthly magazine of the Association of Management and Technology, Danish Marine Engineers).

Reviewing activities

In addition, I have also been reviewing manuscripts for the following scientific journals: *Facilities* and *Building Research & Information*.

Appendix 8

List of presentations

List of presentations

Internal presentations at DTU division meetings (and similar), as well as presentations at courses I participated in, are not included.

Date	**Place**	**Occasion**	**Title** [English translation in brackets]	**Audience**
2016				
December	NTNU, Trondheim, NO	Seminar on sustainable facilities, including sustainable FM.	Who cares for the sustainability perspective? - *Deliberate efforts of holistic and long-term thinking in Danish building processes*	Researchers
2017				
March	DTU MAN	Advisory board meeting	Integration of operational knowledge in energy efficient facilities	Advisory board
March	Sweco, FM division	Division meeting	Integration of operational knowledge in design of energy efficient facilities	FM consultants
May	Roskilde Town hall	Roskilde climate council meeting	Klimavenlig bygningsaflevering i Roskilde Kommune [Climate friendly hand-over in Roskilde Municipality]	Members of the council, mix of academia and industry professionals
May	DTU MAN	FM Researcher Forum	Integration of operational knowledge in energy efficient facilities	Researches and practitioners
August	DTU MAN	Advisory board meeting	Integration of operational knowledge in energy efficient facilities	Advisory board
September	Salford University, UK	CIB World Congress	Transferring knowledge from building operation to design—A literature review	Researchers
September	Copenhagen School of Machine Engineering	Project meeting	Knowledge transfer from FM to building projects	Practitioners, researchers and teachers
September	DTU MAN	Guest lecturer, FM course	FM friendly (new) buildings	Master students
2018				
February	DTU	CFM 10-year anniversary conference	Integrating operational knowledge in building design	Researchers and practitioners
August	DTU MAN	Advisory board meeting	Integration of operational knowledge in energy efficient facilities	Advisory board
September	NTNU Trondheim, NO	Mini seminar	Integration of operational knowledge in energy efficient facilities	Researchers
March	DTU MAN	Advisory board meeting	Integration of operational knowledge in energy efficient facilities	Advisory board

March	Danish Facilities Management (DFM) Network	Annual conference	Two approaches to knowledge transfer	FM practitioners
April	Sweco, FM division	Division meeting	To tilgange til videnoverførsel: Fugl og kuffert [Two approaches to knowledge transfer: Bird and suitcase]	FM consultants
April	Copenhagen School of Machine Engineering	Meeting in FM network within the Association of Marine Engineers.	To tilgange til videnoverførsel: Fugl og kuffert [Two approaches to knowledge transfer: Bird and suitcase]	FM practitioners
April	DTU, MAN	FM Researcher Forum	Tools and methods to establish a feed-forward loop from operation to design of large ships and buildings	Researches and practitioners
May	Sweco, FM division	Division meeting	Tools and methods to establish a feed-forward loop from operation to design of large ships and buildings	FM consultants
June	EFMC 2018, Sofia	Conference	Tools and methods to establish a feed-forward loop from operation to design of large ships and buildings	Researchers and practitioners
June	DFM, Ballerup	Networking event - Global Cafe	Highlights from the EFMC 2018	Practitioners
September	Sweco	Strategic Commissioning Network	To tilgange til videnoverførsel: Fugl og kuffert [Two approaches to knowledge transfer: Bird and suitcase]	Practitioners and consultants
August	DTU, MAN	Stakeholder meeting 4	Integration of operational knowledge in energy efficient facilities	Advisory board
October	NTNU Trondheim, NO	Mini seminar and workshop	A facilities manager's typology of performance gaps	Researchers
November	SBI—Aalborg University Copenhagen	One day conference: 'Byg bro mellem byggeriets parter' [Bridge the actors of the building industry]	To tilgange til videnoverførsel: Fugl og kuffert [Two approaches to knowledge transfer: Bird and suitcase]	Practitioners and researchers
November	DTU	CFM Researcher seminar	A facilities manager's typology of performance gaps	Practitioners and researchers
2019				
February	DTU MAN	Advisory board meeting	Integration of operational knowledge in energy efficient facilities	Advisory board
March	Sweco, FM division	Division meeting	FM vanskeligheder i nye byggerier i DK [FM difficulties in new Danish buildings]	FM consultants
April	University of Copenhagen,	Division meeting	FM vanskeligheder i nye byggerier i DK [FM difficulties in new Danish buildings]	Practitioners

	Campus Service			
May	Copenhagen Business School, Campus Service	Campus Service: Theme meeting	FM vanskeligheder i nye byggerier i DK [FM difficulties in new Danish buildings]	Practitioners
May	Sweco	External network seminar	FM vanskeligheder i nye byggerier i DK [FM difficulties in new Danish buildings]	Practitioners
June	Copenhagen School of Machine Engineering	Meeting in FM network within the Association of Marine Engineers.	FM vanskeligheder i nye byggerier i DK [FM difficulties in new Danish buildings]	Practitioners, researchers and teachers
June	Sweco, FM division	Division meeting	FM vanskeligheder i nye byggerier i DK [FM difficulties in new Danish buildings]	FM consultants
June	EFMC 2019, Dublin	International conference	The legacy from CM to FM	Practitioners and researchers
August	DTU	Advisory board meeting	Integration of operational knowledge in energy efficient facilities	Advisory board
September	Cirre conference, Trondheim, NO	International conference	Comparison of user involvement and operational staff involvement in the design process of a hospital building project	Researchers
September	Region H	A building client's seminar on forthcoming hospital projects	FM og byggeri [FM and construction]	Designers and contractors
September	DTU	FM course, guest lecture	FM in design	Master students

Appendix 9

Co-author statements

Technical University
of Denmark

Declaration of co-authorship at DTU

If a PhD thesis contains articles (i.e. published journal and conference articles, unpublished manuscripts, chapters, etc.) written in collaboration with other researchers, a co-author statement verifying the PhD student's contribution to each article should be made.

If an article is written in collaboration with three or less researchers (including the PhD student), all researchers must sign the statement. However, if an article has more than three authors the statement may be signed by a representative sample, cf. article 12, section 4 and 5 of the Ministerial Order No. 1039, 27 August 2013. A representative sample consists of minimum three authors, which is comprised of the first author, the corresponding author, the senior author, and 1-2 authors (preferably international/non-supervisor authors).

DTU has implemented the Danish Code of Conduct for Research Integrity, which states the following regarding attribution of authorship:

"Attribution of authorship should in general be based on criteria a-d adopted from the Vancouver guidelines[1], and all individuals who meet these criteria should be recognized as authors:

a. Substantial contributions to the conception or design of the work, or the acquisition, analysis, or interpretation of data for the work, *and*
b. drafting the work or revising it critically for important intellectual content, *and*
c. final approval of the version to be published, *and*
d. agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved."[2]

For more information regarding definition of co-authorship and examples of authorship conflicts, we refer to DTU Code of Conduct for Research Integrity (pp. 19-22).

By signing this declaration, co-authors permit the PhD student to reuse whole or parts of co-authored articles in their PhD thesis, under the condition that co-authors are acknowledged in connection with the reused text or figure.

It is **important** to note that it is the responsibility of the PhD student to obtain permission from the publisher to use the article in the PhD thesis[3]

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[1] International Committee of Medical Journal Editors – Recommendations for the Conduct, Reporting, Editing, and Publication of Scholarly Work in Medical Journals, updated December 2016

[2] DTU Code of Conduct for Research Integrity (E-book p. 19)

[3] Many journals will allow you to use only the post-print version of your article, meaning the accepted version of the article, without the publisher's final formatting. In the event that your article is submitted, but still under review, you should of course use the latest submitted version of your article in your thesis. Always remember to check your publisher's guidelines on reuse of published articles. Most journals, unless open access, have an embargo period on published articles, meaning that within this period you cannot freely use the article. Check your publisher's rules on this issue.

Technical University of Denmark

Title of article
Initiatives to integrate operational knowledge in design: a building client perspective.
Journal/conference
Facilities.
Author(s)
Rasmussen, H. L., Jensen P. A., Nielsen S. B. and Kristiansen A. H.
Name (capital letters) and signature of PhD student
Helle Lohmann Rasmussen
PhD student's date of birth
100377
Declaration of the PhD student's contribution
For each category in the table below, please specify the PhD student's contribution to the article as appropriate (please do not fill in with names or x's)

Category	**Minor contribution to the work** *(please specify the nature of the PhD student's contribution)*	**Substantial contribution to the work** *(please specify the nature of the PhD student's contribution)*
Formulation of the conceptual framework and/or planning of the design of the study including scientific questions		Helle developed large parts of the research design.
Carrying out of experiments/data collection and analysis/interpretation of results		Helle carried out the main part of the empirical data. Helle analyzed large part of the data and developed most of the tables and figures
Writing of the article/revising the manuscript for intellectual content		Helle contributed substantially to the writing and revising of the paper.

Signatures

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Technical University of Denmark

Title of article			
Initiatives to integrate operational knowledge in design: a building client perspective.			
Journal/conference			
Facilities.			
Author(s)			
Rasmussen, H. L., Jensen P. A., Nielsen S. B. and Kristiansen A. H.			
Name (capital letters) and signature of PhD student			
Helle Lohmann Rasmussen			
PhD student's date of birth			
100377			
Date	**Name**	**Title**	**Signature**
24-09-2019	PER ANKER JENSEN	ASS. PROFESSOR	Per Anker Jensen
25.09.2019	Helle L. Rasmussen	PhD student	Helle Rasmussen
7-10 2019	Susanne B. Nielsen	Expertise director	Susanne Balslev Nielsen.
08.10.2019	Anders H. Kristiansen	Quality Engineer	Anders H. K.

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Title of article

Knowledge transfer between building operation and building projects.

Journal/conference

Journal of Facilities Management.

Author(s)

Jensen, P. A., Rasmussen, H. L., & Chatzilazarou, S.

Name (capital letters) and signature of PhD student

Helle Lohmann Rasmussen

PhD student's date of birth

100377

Declaration of the PhD student's contribution

For each category in the table below, please specify the PhD student's contribution to the article as appropriate (please do not fill in with names or x's)

Category	**Minor contribution to the work** *(please specify the nature of the PhD student's contribution)*	**Substantial contribution to the work** *(please specify the nature of the PhD student's contribution)*
Formulation of the conceptual framework and/or planning of the design of the study including scientific questions		
Carrying out of experiments/data collection and analysis/interpretation of results	Helle had minor contribution to interpretation of data.	Helle carried out supplementary literature search and analysis to support the findings.
Writing of the article/revising the manuscript for intellectual content	Helle did minor revisions of the paper in accordance with reviewer's comments and proof read the paper before publication	Helle wrote a substantial part of theory section.

Signatures

Title of article			
Knowledge transfer between building operation and building projects.			
Journal/conference			
Journal of Facilities Management.			
Author(s)			
Jensen, P. A., Rasmussen, H. L., & Chatzilazarou, S.			
Name (capital letters) and signature of PhD student			
Helle Lohmann Rasmussen			
PhD student's date of birth			
100377			
Date	**Name**	**Title**	**Signature**
24-09-2019	PER ANKER JENSEN	Ass. professor	Per Anker Jensen
25 09 2019	Helle L Rasmussen	PhD stud.	[signature]
25.09.2019	STAMATIA CHATZILAZAROU	IT Consultant	[signature]

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Technical University of Denmark

DTU

Title of article
Tools and methods to establish a feed-forward loop from operation to design of large ships and buildings.
Journal/conference
Proceedings of EFMC 2018. The EuroFM Conference in Sofia, Bulgaria, June 2018.
Author(s)
Rasmussen, H. L. and Jensen P. A.
Name (capital letters) and signature of PhD student
Helle Lohmann Rasmussen
PhD student's date of birth
100377
Declaration of the PhD student's contribution
For each category in the table below, please specify the PhD student's contribution to the article as appropriate (please do not fill in with names or x's)

Category	**Minor contribution to the work** *(please specify the nature of the PhD student's contribution)*	**Substantial contribution to the work** *(please specify the nature of the PhD student's contribution)*
Formulation of the conceptual framework and/or planning of the design of the study including scientific questions		Helle developed the research design including research questions
Carrying out of experiments/data collection and analysis/interpretation of results		Helle did the literature search and review. Helle developed the interview guide, carried out the interviews, and transcribed the interviews. Furthermore, she coded and analyzed the interviews.
Writing of the article/revising the manuscript for intellectual content		Helle wrote most of the paper, including revising it in accordance with reviewer's comments. Furthermore, she orally presented the paper at the conference.

Signatures

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Title of article
Tools and methods to establish a feed-forward loop from operation to design of large ships and buildings.
Journal/conference
Proceedings of EFMC 2018. The EuroFM Conference in Sofia, Bulgaria, June 2018.
Author(s)
Rasmussen, H. L. and Jensen P. A.
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PhD student's date of birth
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Date	Name	Title	Signature
25-09-2019	PER ANKER JENSEN	ASS. PROFESSOR	Per Anker Jensen
25.09.2019	HELLE L. RASMUSSEN	PhD stud.	Helle Ras

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Title of article
A facilities Manager's typology of performance gaps.
Journal/conference
Under review for publication in Journal of Facilities Management.
Author(s)
Rasmussen H. L., and Jensen P. A.,
Name (capital letters) and signature of PhD student
Helle Lohmann Rasmussen
PhD student's date of birth
100377
Declaration of the PhD student's contribution
For each category in the table below, please specify the PhD student's contribution to the article as appropriate (please do not fill in with names or x's)

Category	**Minor contribution to the work** *(please specify the nature of the PhD student's contribution)*	**Substantial contribution to the work** *(please specify the nature of the PhD student's contribution)*
Formulation of the conceptual framework and/or planning of the design of the study including scientific questions		Helle developed the research design, including research questions
Carrying out of experiments/data collection and analysis/interpretation of results		Helle collected and analyzed data (interviews and workshops). She developed the typology.
Writing of the article/revising the manuscript for intellectual content		Helle wrote most of the paper, including revising it in accordance with reviewer's comments.

Signatures

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Technical University of Denmark

Title of article
A facilities Manager's typology of performance gaps.
Journal/conference
Under review for publication in Journal of Facilities Management.
Author(s)
Rasmussen H. L., and Jensen P. A.,
Name (capital letters) and signature of PhD student
Helle Lohmann Rasmussen
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Date	**Name**	**Title**	**Signature**
24-09-2019	PER ANKER JENSEN	ASS. PROFESSOR	Per Anker Jensen
25 09 2009	Helle L Rasmussen	PhD Stud.	[signature]

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Title of article
The legacy from construction to FM: The good, the bad and the ugly. In
Journal/conference
In: Proceedings for EFMC, Dublin 2019
Author(s)
Rasmussen, H.L. and Due, P.H.,
Name (capital letters) and signature of PhD student
Helle Lohmann Rasmussen
PhD student's date of birth
100377
Declaration of the PhD student's contribution
For each category in the table below, please specify the PhD student's contribution to the article as appropriate (please do not fill in with names or x's)

Category	**Minor contribution to the work** *(please specify the nature of the PhD student's contribution)*	**Substantial contribution to the work** *(please specify the nature of the PhD student's contribution)*
Formulation of the conceptual framework and/or planning of the design of the study including scientific questions		Helle developed the research design, including research questions and data collection technique.
Carrying out of experiments/data collection and analysis/interpretation of results		Helle formulated the majority of the survey questions and took part in testing of the questionnaire. Helle managed the web-based questionnaire and the carried out the following analysis.
Writing of the article/revising the manuscript for intellectual content		Helle wrote the most of the article. Furthermore, she revised the paper in accordance with reviewer comments. Furthermore, se orally presented the paper at the conference.

Signatures

Technical University of Denmark

Title of article
The legacy from construction to FM: The good, the bad and the ugly. In
Journal/conference
In: Proceedings for EFMC, Dublin 2019
Author(s)
Rasmussen, H.L. and Due, P.H.,
Name (capital letters) and signature of PhD student
Helle Lohmann Rasmussen
PhD student's date of birth
100377

Date	Name	Title	Signature
26/9-19	POUL HENRIK DUE	MR.	[signature]
3/10-19	Helle Lohmann Rasmussen	PhD student	[signature]

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