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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 than 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	<i>Ships</i>			<i>Buildings</i>	
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 m².

In addition, space in the existing airport buildings were included in the project, adding up to 12.000 m². 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 m². 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	<i>Ships</i>			<i>Buildings</i>	
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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