Knowledge-Based Management Challenges in the Asset Life Cycle

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Abstract: This study examines knowledge-based management challenges at different stages of the asset life cycle in project networks. The case network is the infrastructure construction sector, which includes organizations in design, construction and maintenance. This sector forms an interesting case as there are multiple problems related to knowledge-based management. By comparing the maturity levels of the different stages of the asset life cycle, we aim to identify the major challenges in knowledge-based management in asset life cycles within the infrastructure sector. A maturity survey on knowledge-based management was distributed to 22 organizations, generating 68 respondents. The respondents worked in infrastructure sector organizations at different stages of the asset life cycle, including design, construction and maintenance. The findings of the survey were compared, so as to present relevant issues at each stage, and analysed with a framework suggested for the maturity model. There is little research on knowledge-based management relating to the asset life cycle. Therefore, this study creates new knowledge in this area and enhances understanding of how issues of knowledge-based management differ in the stages of the life cycle as a manifestation of knowledge management. Organizations in the infrastructure sector gain valuable information on the issues that need to be fixed so as to gain more value from digitalization. This research is part of the ProDigial research programme whose practical contribution will be a manual on knowledge-based management for asset-managing organizations.

Keywords: Knowledge-based management, maturity model, asset life cycle

1. Introduction

In recent decades, there has been marginal productivity development in the infrastructure construction sector, which includes building public structures such as roads and bridges. Vaismaa et al. (2020) scrutinized productivity in the asset life cycle of the infrastructure construction sector and found that there were knowledge-based management (KBM) related challenges and bottlenecks affecting productivity and digitalization therein. In other words, fixing KBM-related challenges may advance digitalization and increase the productivity of the infrastructure construction sector. As Myllärniemi et al. (2019) put it, organizations can advance digitalization by refining data or information to knowledge so as to improve their decision-making capabilities and productivity. Digitalization involves dealing with organizational data and information resources with dedicated tools and techniques (Hellsten and Paunu, 2020). However, KBM-related challenges have received very little research attention in the infrastructure sector, especially in relation to the asset life cycle.

The infrastructure sector is fragmented, complex and project-based. The life cycle of assets in the project environment is complex as multiple organizations need to cooperate in the context of co-dependent lifecycle stages: design, construction and maintenance. In addition, the asset life cycle can be decades long, for example, that of a bridge. These characteristics imply asset lifecycle-related challenges in the sector in terms of capturing and reusing valuable knowledge gathered during projects. According to Vaismaa et al. (2020), sector operators are ‘siloed’, that is, they may have little fluent communications with their ‘neighbours’ or co-operators. Similarly, the information on which the decision-making is based may be false or may change, and organizations often have unused knowledge. Based on the findings of Vaismaa et al. (2020), KBM plays a significant role in increasing productivity in the field. Similarly, Lawson et al. (2009) found that KBM in projects with multiple actors, as in the infrastructure construction sector, can decrease asset lifecycle costs.

Based on Vaismaa et al. (2020), information and its correct handling are two of the main components of productivity in the infrastructure construction sector. The sector is eager to utilize the solutions that digitalization provides, for example, the Internet of things, big data, artificial intelligence and building information modelling (BIM). In particular, BIM is widely used in building and infrastructure projects (Chong et al., 2016). However, it implies weaknesses in relation to KBM, such as erroneous or missing information (Nývlt and Prûsková, 2017). There are multiple challenges regarding knowledge management and KBM, as manifested in the infrastructure construction sector, that need to be addressed before digitalization can deliver value.

In this study, we sought to identify the major KBM challenges relating to the asset life cycle in the infrastructure construction sector. Our research questions are as follows:

1. Which KBM challenges relating to the asset life cycle in the infrastructure construction sector can be identified?
2. Do the stages of the life cycle have distinctive challenges that hinder KBM in relation to the asset life cycle?

We conducted a maturity survey of KBM in the infrastructure construction sector, which included the various stages of the asset life cycle, to understand the current state of KBM relating to the asset life cycle in the sector. The survey focused on KBM practices undertaken during infrastructure projects, and the study context was the Finnish infrastructure construction sector. It should be noted that customer organizations in the infrastructure construction sector in Finland are always public. Therefore, this study takes place in the intersection of the public sector and private companies. However, the cooperation dynamics between private and public actors are not discussed.

As a practical contribution, organizations in infrastructure construction will gain valuable knowledge on the KBM-related challenges they will need to overcome to advance digitalization. The theoretical contribution involves creating new knowledge on how KBM challenges vary in each stage of the asset life cycle as there is a dearth of research on KBM relating to the asset life cycle.

In the next section, we illuminate the existing research and theoretical presumptions concerning KBM and the asset life cycle in the infrastructure construction sector. Section three presents the methodology of the study and data collection. Section four presents the findings, while section five discusses the results in the context of the existing research. Section six concludes the research.

2. Related research

2.1 Knowledge-based management

Digitalization has been responsible for changing operational landscapes (Reis et al., 2019). It involves the creation and execution of 'changes associated with the application of digital technology in all aspects of human society' (Stolterman and Fors, 2004, p. 23). This generally covers a range of organizational activities. The changes and trends involved affect the whole organization from the individual level (i.e. how personal communication is conducted) to the operational level (i.e. how the organization functions communicate) (Bloomberg, 2018). Thus, it becomes a question of angle and viewpoint in terms of defining more closely what exactly is under scrutiny. Digitalization is connected to all business processes of an organization because it is only through this connection that the organization can draw high-quality information from activities and form information products from actual proceedings to lay foundations and bring value to decision-making. Digitalization most often deals with the operational data and information of organizations. It is a proven tool to improve organizational operations and in enabling knowledge management operations.

Knowledge management (KM) is an approach through which the various forms of knowledge content within an organization may be identified and taken into use (Nonaka and Toyama, 2007; Nonaka and Takeuchi, 1995). This use includes decision-making or planning at various operational levels and managing daily working routines. A central objective of this approach is to offer the right information or knowledge at the right time to those who need it for the purpose of decision-making. To accomplish this, the organization needs not only the appropriate technological infrastructure and necessary processes but also the right employee mindset, that is, the right combination of attitudes and skills to make things happen (Jääskeläinen et al., 2022). KM is an approach in which management considers both technological issues and human aspects when making decisions to promote organizational goal-setting (Girard and Girard, 2015). Conversely, KBM is a derivative of KM. In a way, the knowledge-based view of the firm is brought back into the conversation when one considers the role that knowledge plays in the organizational context and how it is best utilized (Grant, 1996). Knowledge content may be derived from both inside and outside the organization, thus underlining the holistic nature of KM. The main point in KBM is the very use of the knowledge assets that one has access to, giving even more significance to the way in which organizations need to recognize and acknowledge what knowledge is needed, relevant and obtainable. Similarly, organizations need to distinguish how knowledge needs to be effectively processed and shared within the organization and, where appropriate, with other stakeholders and how knowledge can be used in decision-making (Choo, 1996; Kaivo-oja et al., 2015; Thierauf, 2001).

Challenges in KBM include technical issues caused by unsuitable infrastructure, data quality, human issues such as reluctance to share knowledge and biases in thinking or even inefficiency issues in work processes (Väyrynen et al., 2017). In addition, the life cycle of assets in projects involving multiple organizations creates additional challenges for KBM: the various information systems might be misaligned, and employees might not share their knowledge outside their organization (Vuori et al., 2019). KM and the more pragmatic KBM have gained interest among researchers in projects involving multiple actors (Lancini, 2015; Agostini et al., 2020), similar to those in the infrastructure construction sector However, much of the existing research focuses on one area of KBM at a time, such as knowledge creation, knowledge sharing or knowledge acquisition. To a lesser extent, all stages, from identifying knowledge needs to knowledge utilization in the KBM process, have been depicted (Jääskeläinen et al., 2022). The KBM process can be divided into multiple sections: identifying information and knowledge needs, information acquiring, organizing and storing information, forming information products, sharing information and knowledge and using information in decision-making. The final stage is to make the necessary decisions and see them through in the organization, that is, knowledge use for organizational learning (Choo, 2002; Vitt et al., 2002).

There are ways in which to study KBM in an organization. One such tool is that of Jääskeläinen et al. (2022), which is based on the principles presented in Choo (2002). This tool makes it possible to scrutinize the state of KBM in an organization, after which development plans can be drawn as viewpoints are distinguished according to the breadth of the scrutiny.

2.2 Asset life cycle in the infrastructure construction sector

The life cycle of an asset in the infrastructure construction sector can be divided into various stages: design, construction and maintenance. In the design stage, the infrastructure is designed to the point where it can be constructed. Following the construction of the design, the structure is maintained, sometimes for decades. Figure 1 visualizes the asset life cycle and case project network. In each stage, private companies and customer organizations operate simultaneously in multiple projects while partnering with different organizations.

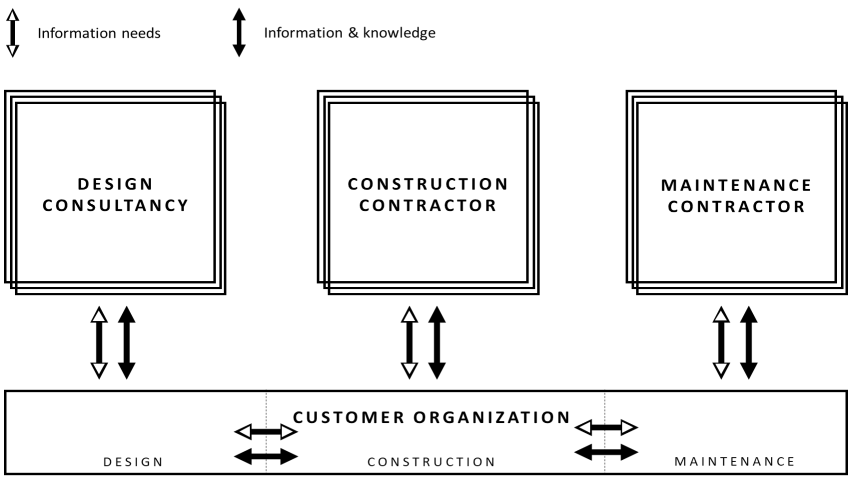

Figure 1: Asset life cycle and case project network

According to Muller et al. (2019), most tools used in design are unsatisfactory as they are not suitable or sufficiently flexible for rapid design processes; for example, it is difficult to share up-to-date information about simulations. KBM challenges, especially in terms of information sharing, are important as communication among actors and consistent reviews are essential for successful design (Zanni et al., 2014). Inadequate design documents create problems, especially if the construction does not update the design documents as 'built', as there might be costly maintenance effects if there is no information on what has been constructed (Muller et al., 2019). Love et al. (2014) pointed out that even a small change in a design decision can cause costly alterations in construction and maintenance stages. Construction efficiency can be improved by having information correspond with the physical infrastructure (Li and Cao, 2020). Chen and Lu (2019) maintained that information quality, quantity and accessibility are significant factors for successful KBM in construction. In addition, construction has faced difficulties in implementing practices and information sharing, which have hindered the development of KBM (Azhar, 2011).

Information is a critical factor in efficient and effective maintenance. However, it is laborious to acquire information for maintenance (Pärn et al., 2017). For the same reason, information is not always reliable as it might not be up to date (Lin et al., 2022). There can be a positive impact on lifecycle costs if the maintenance is done dynamically within the asset life cycle (Wong and Zhou, 2015), as a majority of the costs are formed in the stage of maintenance (Pärn et al., 2017). Xun et al. (2015) provided an example of unfunctional KBM and undynamic cooperation in the case of BIM, which is a digital representation of the physical characteristics of a built object (Volk et al., 2014). BIM can be used across the asset life cycle to improve simulation and analysis, collaborative working and information management (Liu et al., 2015). According to Xun et al. (2015), the BIM model from a previous stage is not delivered to the subsequent stage. Instead, a BIM is built for each stage. Since the infrastructure construction sector is fragmented and project-based, it makes KBM implementation difficult, a point made by Arayici and Aouad (2010) in the context of building construction. In addition, the complexity of the asset life cycle creates special documentation requirements (Wong and Zhou, 2015). Owen (2010) has stated that codified information and knowledge mainly exist within functions and other individual groups and are not shared sufficiently frequently with other partners. Currently, KBM is less than ideal in terms of the asset life cycle (Nývlt and Prúsková, 2017; Liu et al., 2009).

3. Methods

The research was conducted by distributing a survey to 22 organizations in the infrastructure construction sector in Finland. The organizational participants were companies and public customer organizational participants of the research program ProDigial. In total, we received 68 responses to this survey, which dealt with the various stages of the asset life cycle: design, construction and maintenance. The respondents were grouped according to these three stages, with each stage including respondents who reportedly worked therein. There were 18 respondents in design, 21 in construction and 12 in maintenance. The remainder of the respondents (17) reported having a more holistic view on the life cycle. Their responses were not included in this study as they will be discussed in further research.

The survey is based on a maturity model of information and knowledge management (Jääskeläinen et al., 2022). The survey questions were modified to better describe KBM instead of information and knowledge management. Except for the section on vision and strategy, which focused on the organizational level, the respondents were encouraged to consider common infrastructure construction projects instead of their own organization as a way to get them to think about cooperation in the asset life cycle.

In the survey, KBM was divided into eight sections: vision and strategy of an organization (A), governance and organization of a project (B), information needs in a project (C), information acquisition in a project (D), information organization and storage in a project (E), information products in a project (F), information and knowledge sharing in a project (G) and information usage in a project (H). Each of these sections included between five and ten statements on the development of practices. In addition, one statement addressed the satisfaction with the section. The respondents provided answers to these statements on a 5-point Likert scale: whether they strongly disagreed (1), somewhat disagreed (2), were neutral (3), somewhat agreed (4) or strongly agreed (5). They could also choose not to answer a statement. The responses were grouped into two categories – agree and disagree – because it is difficult to analyse the difference between strongly and somewhat agree or disagree and neutral as the intervals between these values could not be presumed as qual (Cohen et al., 2007). In addition, there were a few responses for strongly disagree or strongly agree, and it was assumed that grouping them would not have a notable impact on the results. After the grouping, the distribution of responses depicting agreement and disagreement was calculated as a percentage while leaving out the neutral responses. The percentages representing the satisfied and unsatisfied respondents were based on a single statement. The percentages for the responses agreeing with the development of each KBM section were based on five to ten statements each.

Jääskeläinen et al. (2022) proposed a framework for analysing maturity surveys, which was used in this study to analyse the results. The framework forms a 2 × 2 matrix, which included developed and undeveloped as well as dissatisfactory and satisfactory practices. As shown in figure 2, there were four levels of maturity: novice, facilitator, experimenter and advanced exploiter. Each KBM section was placed in this framework for each stage of the asset life cycle. Whether the KBM section included developed or undeveloped practices was determined from the distribution between the responses agreeing and disagreeing with the practices being developed: if more than 50% thought that practices were being developed, the section was placed on the experimenter or advanced exploiter level. If more than 50% of the respondents were satisfied with a KBM section, it was placed on the advanced exploiter or facilitator level.

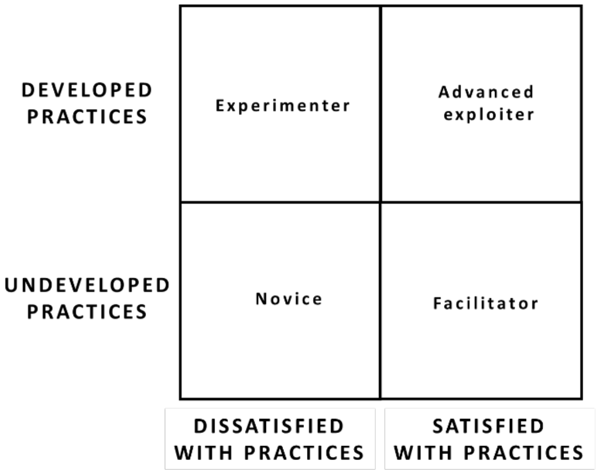

Figure 2: A framework for analysing the KBM maturity survey (Jääskeläinen et al., 2022)

The desired level is that of the advanced exploiter, where KBM practices are well-developed and meet the needs of the organization. Reaching the facilitator level is also positive because even if the practices are not quite developed, they are sufficient for the organization's needs. Being on the experimenter level implies that the practices are well developed, at least on the strategic level; however, either the practices do not satisfy the needs of the organization or they have not been successfully implemented. The novice level means that the organization's practices are in a primitive stage and that it should focus on developing these practices. (Jääskeläinen et al., 2022). In this study, instead of analysing each organization separately, each KBM section was placed separately in this framework, and the results were analysed based on the three stages of the asset life cycle.

4. Results

The results are presented in two tables. Table 1 presents the percentage of responses in agreement with the development of the KBM practices in the design, construction and maintenance stages. The percentages of respondents who were satisfied with each section of KBM are presented in table 2. Since the percentages in table 1 present the responses in agreement with the KBM practices being developed, a percentage that was less than 50% meant that there were more responses disagreeing with the KBM practices being developed. When the responses were equally distributed between the categories representing agreement and disagreement, the practices were interpreted as undeveloped because there was clearly a significant number of respondents who thought that the practices were not sufficiently developed.

Table 1: The percentage of responses in agreement with the development of the KBM practices

Sections of KBM	Design	Construction	Maintenance
A. Vision and strategy of an organization	80%	81%	79%
B. Governance and organization of a project	56%	49%	55%
C. Information needs in a project	66%	68%	77%
D. Information acquisition in a project	73%	69%	70%
E. Information organization and storage in a project	70%	54%	68%
F. Information products in a project	51%	50%	64%
G. Information and knowledge sharing in a project	60%	70%	70%
H. Information usage in a project	74%	78%	83%

The respondents in the design stage clearly agreed with the practices being developed in the sections of vision and strategy at the organizational level and information usage at the project level, with responses depicting agreement reaching at least three-quarters. The result regarding information products was quite controversial, showing that slightly more respondents considered the practices being developed. None of the KBM sections were clearly undeveloped in any of the stages of the asset life cycle; however, in construction, the sections covering governance and organization of projects and information products can be interpreted as having undeveloped practices. In construction, there was clear agreement regarding the development of vision and strategy and information usage. The result was similar for maintenance, but there was also clear agreement regarding the development of practices pertaining to information needs. Overall, maintenance had the highest agreement percentages regarding the development of practices.

As mentioned earlier, each section on the survey included one statement on the respondents' satisfaction with the KBM section. The percentages of satisfied respondents are presented in table 2. A percentage of less than 50% indicated that more respondents were unsatisfied with the practices in the KBM section. In the case of responses being equally distributed between satisfied and unsatisfied respondents, the respondents were interpreted as unsatisfied.

Table 2: The percentage of respondents who were satisfied with the KBM practices

Sections of KBM	Design	Construction	Maintenance
A. Vision and strategy of an organization	50%	62%	60%
B. Governance and organization of a project	18%	42%	56%
C. Information needs in a project	46%	64%	45%
D. Information acquisition in a project	50%	64%	56%
E. Information organization and storage in a project	50%	50%	40%
F. Information products in a project	62%	57%	44%
G. Information and knowledge sharing in a project	50%	69%	44%
H. Information usage in a project	60%	69%	57%

The percentages representing satisfied respondents create interesting contrast to the seemingly developed practices. Whereas the percentages depicting agreement with the practices being developed mainly exceeded 50%, the percentages representing satisfied respondents were often 50% or less, indicating that the respondents were unsatisfied with the current state of these KBM practices. In addition, none of the stages had sections containing a remarkable number of satisfied respondents. In design, the respondents were notably unsatisfied with the governance and organization of projects. They were also unsatisfied with vision and strategy at the organizational level, information needs, information acquisition, information organization and storage and information and knowledge sharing. The satisfied respondents in construction represented a majority in most of the sections, with the only exceptions being the governance and organization of projects and information organization and storage. Of the three stages, construction seemed to have the most satisfied respondents. Maintenance had more unsatisfied respondents in the sections of information needs, information organization and storage, information products and information and knowledge sharing.

5. Discussion

The results were analysed using the framework presented in chapter 3. Clear differences – and interesting similarities – were found in the comparison of the design, construction and maintenance stages. They are shown in figure 3. For all stages of the life cycle, there were similarities in information usage (H) and information organization and storage (E), the first being at the advanced exploiter level and the latter at the experimenter level. The maturity levels of the KBM sections of construction and maintenance had in common organizational vision and strategy (A) and information acquisition (D), both of which were at the advanced exploiter level. Design and maintenance both had practices for identifying information needs (C) at the experimenter level. The KBM design sections were mostly at the experimenter level, except for creating and utilizing information products (F) and information usage (H), which were both at the advanced exploiter level. In maintenance, the KBM sections were equally distributed between the experimenter and advanced exploiter levels. Therefore, maintenance had a slightly better KBM situation than design. There was an interesting situation in construction. Most of the KBM sections were at the advanced exploiter level, but they had undeveloped practices relating to governance and organization of projects (B) and creating information products (F). However, the marginal development of creating information products did not seem to disrupt construction which seemed to fulfil its needs, at least to some degree, as this section reached the level facilitator. Information organization and storage (E) was on the experimenter level.

It should be noted, however, that in the KBM sections of design and maintenance at the advanced exploiter level, the percentages of satisfied respondents were between 56% and 62%, and therefore, there was still a significant number of unsatisfied respondents. Consequently, it could be argued that the overall KBM maturity level of design and maintenance remained at the experimenter level since at least half of the other sections were already considered to be at this level. Construction had slightly better satisfaction rates, reaching 69% in two of the sections, and most of the KBM sections were at the advanced exploiter level. Even if construction reached the advanced exploiter level with unsignificant satisfaction, it can be argued that their KBM maturity was at a better level than that of design and maintenance.

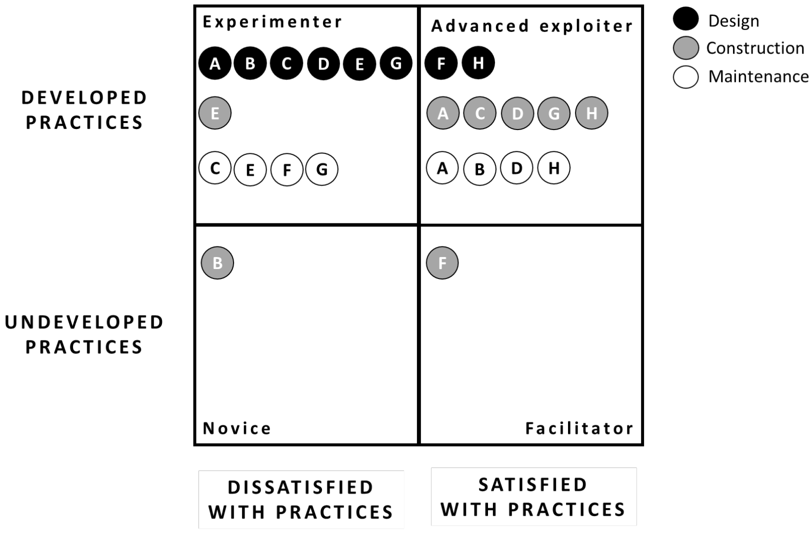

Figure 3: KBM in the different stages of the asset life cycle

Reaching the experimenter level indicates that the practices were not developed according to the needs of the employees or that the implementation of the practices was not successful (Jääskeläinen et al., 2022). As design is at the experimenter level, it seems that design has practices and tools to support their work but that the tools and practices do not meet their needs. This is well in line with the findings of Muller et al. (2019), who reported that while design has tools, they are not sufficiently suitable and flexible. Zanni et al. (2014) raised the importance of information sharing for successful design, and according to their results, information and knowledge-sharing practices (G) are unsatisfactory and need to be developed further. Another issue with design is the need to make changes to design decisions and the provision of inadequate design documents in the construction context (Love et al., 2014; Muller et al., 2019). These issues can be related to unsatisfactory information acquisition (D) or information needs identification (C) practices as it is difficult to make the right decisions with insufficient information. The results pertaining to maintenance contradict those in the literature. Pärn et al. (2017) noted the laboriousness in acquiring information in maintenance, but this was not clear in our results as information acquisition (D) reached the advanced exploiter level, although with only a 56% level of satisfaction. In addition, Lin et al. (2022) stated that information is not updated in maintenance, which suggests that information organization and storing practices (E) are not very developed. These results suggest, however, that the section was quite developed, with 68% agreement on development, despite being satisfactory to the employees.

According to Azhar (2011), construction has faced challenges in implementing practices. However, the current results suggest quite the opposite: construction was most successful in implementing practices compared to design and maintenance, with construction reaching the level of advanced exploiter in most of its KBM sections. According to Jääskeläinen et al. (2022), advanced exploiters have developed KBM practices, which are successfully implemented. However, construction did have its share of KBM challenges. The practices in the governance and organization of projects (B) were undeveloped and unsatisfactory. As information quality and accessibility are key factors for successful KBM in construction (Chen and Lu, 2019), the results suggest that construction has challenges relating to information quality and accessibility as the respondents were not satisfied with their information organization and storage practices (E). Construction can increase efficiency with tools such as BIM, in which information corresponds to physical infrastructure (Li and Cao, 2020), but erroneous or missing information is a significant factor in BIM-related problems (Nývlt and Prûsková, 2017). Therefore, it could help if construction increased efficiency to improve information organization and storage practices (E). None of the stages of the asset life cycle recorded satisfaction with information organization and storage practices (E). In addition, design and maintenance recorded challenges with acquiring (D) and sharing (G) information. These results indicate that the information systems between the organizations might have been misaligned, a common problem identified by Vuori et al. (2019) in projects involving multiple organizations. This misalignment, according to Xun et al. (2015), can result in BIM models not being delivered from one stage to the next.

6. Conclusions

As the survey results show, there are difficulties in implementing KBM practices, especially in design and maintenance, and that the focus should be on these KBM challenges. However, as mentioned in chapter 2, the fragmented and project-based nature of the infrastructure construction sector makes the implementation difficult. Construction should improve information organization and storage as well as project organization. All stages in the asset life cycle would benefit from a better alignment of their information systems and more dynamic cooperation overall.

It should be noted that the organizations participating in the maturity survey took part in the ProDigial research programme, which focused on digitalization, KBM and the productivity leap. Therefore, organizations interested in participating in such research are not the least motivated in terms of digitalizing their operations. Since it is more likely to be the opposite, our results potentially show the maturity level of KBM in the most developed organizations in the Finnish infrastructure construction sector. In this case, the field consists of organizations, especially in maintenance, that could be benchmarked for developing other organizations at the same stage of the asset life cycle.

This research contributes new knowledge on KBM in the infrastructure construction sector and the asset life cycle. It provides insights on current KBM challenges in the stages of the life cycle. Organizations in the infrastructure sector will gain valuable information on which issues to fix in order to gain greater value from digitalization. The practical contribution of the study relates to the output of the ProDigial research programme as the corresponding research will be utilized to create a manual on KBM for asset-managing organizations. Furthermore, future research will take a closer look at the challenges in the infrastructure construction sector in an effort to seek solutions to these challenges. The details of the KBM challenges in relation to the asset life cycle should be further examined with a view to finding potential solutions.

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