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Maintenance capability creation for buildings – concurrent process with design and construction

Petteri Annunen, Juho Tella, Sini Pekki and Harri Haapasalo
Department of Industrial Engineering and Management, University of Oulu, Oulu, Finland

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Abstract

Purpose – This study describes how maintenance capability should be created during the design and construction phases of construction projects. Purpose of the abstract to define the elements for creating the maintenance capability and the process to be used in construction life cycle projects for buildings.

Design/methodology/approach – An inductive and qualitative research method was used to construct the proposed process based on the literature and 18 interviews in two large construction companies.

Findings – The results indicate that the maintenance phase is usually overlooked during the design and construction phases, and capabilities are not systematically built. In particular, processes are lacking in data management, causing severe problems in maintenance.

Originality/value – This study presents a process including key requirements and activities for creating maintenance capability in conjunction with the design and construction phases, which is novel to the literature. The validated process can be adapted based on the needs of the construction company.

Keywords Construction, Maintenance, Maintenance capability creation, MCC, Data management, Life cycle management, Early involvement

Paper type Research paper

1. Introduction

The construction and real estate sectors have been suffering from several known problems, hindering the development of productivity (Dave, 2017; Halttula *et al.*, 2017). One of the key deficiencies has been a lack of cooperation between life cycle phases, where information transfer has been insufficient and, in particular, has been incomplete in the later phases (Harkonen *et al.*, 2019; Halttula *et al.*, 2020). Several studies report information- and quality-related maintenance problems arising in the design and construction phases (Waziri, 2016; Hassanain, *et al.*, 2019; Ebekozien *et al.*, 2022; Hauashdh *et al.*, 2022), and life cycle costs and maintenance have been studied extensively (Ebekozien, 2021).

The maintenance phase accounts for a major part of the total lifetime costs of a building (Heaton *et al.*, 2019), highlighting the importance of this phase. Some of the key challenges related to data are addressed by building information modelling (BIM) systems aiming at digitalisation, but the original building data are still often delivered as portable document

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format files or even in a paper form to the maintenance phase (Gao and Pishdad-Bozorgi, 2019). Lean methods are enabling development by widening the focus from the design and construction phases to the whole life cycle though value streams (De Silva *et al.*, 2012), but methods for concretely involving maintenance during the earlier project phases are lacking (Ganisen *et al.*, 2015).

One reason for omitting maintenance requirements is the contract models used in the industry. In traditional contracts (e.g. design–build [DB], design–bid–build [DBB]), the maintenance phase is usually managed by different stakeholders than in the design and construction phases. Without good co-operation between the phases and without proper processes, it is difficult to manage the shift from one phase to another, especially between two companies (Annunen *et al.*, 2021). Life cycle contract models (e.g. design–build–own–operate–transfer [DBOOT]) include all the phases from design to maintenance, and all are managed by one stakeholder, seeking a tighter connection between phases (Kerosuo *et al.*, 2012).

Life cycle contracts in the Finnish construction industry refer to projects in which the customer and contractor make a longitudinal agreement on the design, construction and maintenance of a building. Typically, the maintenance phase in these projects covers 20–25 years (Kerosuo *et al.*, 2012). Finnish construction projects are managed with a Finnish national Building Information File (RT 103166, 2020) and facility maintenance with a Property Management File (KH 90–00612, 2016). In life cycle contracts, the importance of maintenance capabilities is specified from the beginning of the project, as the same company must also cover the life cycle costs (Kerosuo *et al.*, 2012).

Capability creation (CC) processes are used in global manufacturing industries to support the systematic involvement of later project phases in parallel to the product design phase (Tolonen *et al.*, 2017; Annunen *et al.*, 2021). However, application to the construction industry has been limited. There is a considerable amount of literature on maintenance capabilities in construction, but information about when and how they should be created is rare. Therefore, the main aim of this article is to create a foundation for CC processes for the maintenance phase of a construction project. This leads us to the research questions of the study.

RQ1. What are the key elements in creating capabilities for maintenance?

RQ2. What are the main challenges in the maintenance phase?

RQ3. What is the main setup for the maintenance CC (MCC) process, especially in life cycle projects?

We began the study with a literature review on life cycle management, data management, early involvement and CC processes, resulting in key preconditions for creating maintenance phase capabilities in the construction industry (*RQ1*). The literature review also compiles the elements and sub-elements for maintenance. After the literature review, we present the research process and method for two semi-structured interview rounds. In the empirical section, we first analyse the challenges of the maintenance phase (*RQ2*) based on first interviews and then present requirements for the MCC process (*RQ3*) based on the literature and, specifically, on second interviews. Finally, we validate the process in company A, which is implementing buildings with the life cycle model.

2. Literature review

2.1 Building and data life cycle management

Product life cycle management (PLM) refers to business management, where products of the company are managed efficiently during their whole life cycle (Stark, 2015). It is crucial to recognise processes and resources from the initial business idea to the removal of the product. PLM needs to cover all these phases, and all phases should have requirements to produce data, whatever project model is used (Crnkovic *et al.*, 2003; Stark, 2015). Crnkovic *et al.* (2003) define seven phases of the product life cycle: business idea, requirement management, development, production, use, maintenance and removal of the product. In construction, the product life cycle typically includes four key phases: preplanning, design, construction and maintenance (Halttula *et al.*, 2020). The maintenance phase includes real estate maintenance as well as facility and user services (KH X9-00526, 2013).

The target of life cycle management is to coordinate and manage the product data and processes of the company. This basically means that the processes and product data management (PDM) must be in line with the vision and targets of the company (Saaksvuori and Immonen, 2008). The life cycle is managed through information management systems. PLM systems enable ideal situation information and process management through a centralised data system, which can be used by all the organisational and business processes of the company (Tolonen *et al.*, 2017). In construction, the use of BIM is growing for this purpose, although it is not yet fulfilling all of its promise (Jupp, 2013; Dahanayake and Sumanarathna, 2022; Mansoori *et al.*, 2022). PLM requires PDM to manage the products through the whole life cycle, ensuring efficient business processes (Giménez *et al.*, 2008).

Data governance includes data quality, consistency, security, usability and availability (Halttula *et al.*, 2020). Managing and maintaining data require appropriate organisation, and the data owner plays an especially important role (Silvola *et al.*, 2019). Digitalisation aims to enhance and reform business by making the processes more efficient. The construction industry is embracing digitalisation, and BIM is seen as one solution to improve both digitalisation and poor productivity development – although with more discussion than practical implementation so far (Halttula *et al.*, 2020). Missing data, software problems and mismatch of the current data systems are still problems in the industry, especially in the latter parts of the construction product life cycle (Gao and Pishdad-Bozorgi, 2019; Sulaiman *et al.*, 2021; Mansoori *et al.*, 2022). According to Eastman *et al.* (2008) and Halttula *et al.* (2020), the focus in BIM development should not be on technical issues but rather on processes throughout the whole construction project. BIM does not solve process-related problems.

2.2 Early involvement with capability creation processes

Most construction projects are complex by nature, involving several stakeholders, which leads to some known problems in processes, trust and information sharing (Aapaoja and Haapasalo, 2014). One of the root causes for problems is a lack of collaboration during the design and construction processes (Love *et al.*, 2004), causing unnecessary costs for the maintenance phase (Islam *et al.*, 2021). Early involvement of key stakeholders in the front-end project phases can help with these problems. The utilisation of collaborative project models has led to the adoption of quality and lean practices and proven supply chain concepts in the construction industry (Hietajärvi and Aaltonen, 2018; Halttula *et al.*, 2020).

Dave (2017) highlights the importance of well-managed operational processes in the construction industry. Processes should not be just created but also followed, maintained and managed well through all the operations. Operational processes require defined governance and ownership, and especially in larger projects, the processes need to be divided into stages with the following gates to ensure that the key activities defined for each stage have been completed in a proper manner (Ulrich and Eppinger, 2008). Stage-gate models are commonly used in the manufacturing industry, usually with five to seven stages and respective gates during the new product development, namely, discover, scoping, business plan concept, development, testing and validation, launch and implementation are the most common stage definitions (Cooper, 2011). Gate reviews are viewed as a way to control processes when all elements or outputs have not been defined accurately (Kess and Haapasalo, 2002).

Tolonen *et al.* (2017) describe CC processes as a solution to build the capabilities for the later project phases in the design phase. Verrollot *et al.* (2017) agrees that one of the success factors of product development is integrating receiving business processes, such as delivery, production or maintenance processes, in the product development or design process. Isoherranen and Majava (2018) argue that it is essential to create maintenance and care capabilities during product development. If the maintenance requirements and needs are not established in the early phases of the project, they are more difficult and require more to achieve later (Isoherranen and Majava, 2018).

Key preconditions for implementing successful CC processes include the following (Tolonen *et al.*, 2017; Verrollot *et al.*, 2017; Annunen *et al.*, 2021):

- Key operational processes need to be in place, including not only design, production and maintenance processes but also quality management, product management and data management processes.
- Synchronising CC processes with key business processes, including stages, gates and common key metrics.
- The requirements of later project phases need to be part of earlier project phases, i.e. maintenance process requirements need to be part of the design and construction stages and gate reviews.
- Governance and roles, including global process owners for the CC processes, need to be in place.

2.3 Synthesising capability creation to maintenance requirements

Fragmentation of activities and stakeholders have been seen as the root cause of the most serious problems in the construction industry (Tampio *et al.*, 2022; Tampio and Haapasalo, 2022). From a data management point of view, the biggest problem is weak data and information interoperability and flow through the whole project life cycle (Halttula *et al.*, 2020). This increases the importance of managing (planning, organising, leading and controlling) the whole construction project properly from the design phase to maintenance phase (Weeks and Leite, 2021). Training and increased information availability are key for building the competencies of the organisation and decreasing resistance to change (Saaksvuori and Immonen, 2008; Lavy and Jawadekar, 2014).

Efficiency in use and maintenance lead to the final excellence of a product (building) during the entire life cycle – that is, how the building serves the purpose it was originally designed for or in some cases modified for. However, the specification of a product (a house) is defined during the design, with relatively little possibility to impact the content during use and maintenance. In construction, life cycle assessment, maintenance activities and periods are familiar concepts, even at the level of regulations or instructions (Ebekozien, 2021). What has received less attention is how maintenance capabilities could be created in the design and construction phases (Ganisen *et al.*, 2015).

The MCC method aims to plan and create key capabilities for maintenance during the early phase to ensure efficient use of the building. The MCC process aims for a more accurate value creation structure to achieve this target (Tolonen *et al.*, 2017; Annunen *et al.*, 2021). Regulations and industry standards must be considered when initiating CC processes for national building life cycle laws (Harkonen *et al.*, 2019). In Finnish construction, this basically means Building Information and Property Management Files and some other national regulations, such as instructions for detailed maintenance phase documentation (Pirinen and Kukkonen, 2001). The literature introduces more detailed elements regarding the capabilities required during maintenance, but it does not explain how and when these can be achieved or how and what define these elements. Parallel to our conceptual development based on earlier research, we have conducted a literature review on facility maintenance (12 main elements, a description of which is been presented in the Appendix Table A1).

3. Research process and method

An inductive and qualitative research method was applied in this study (Figure 1), following Bryman and Bell (2011). In the first phase of the study, a literature review was conducted to establish a conceptual foundation for MCC and respective maintenance elements. Second, semi-structured interviews were used to reveal the most important challenges in the two case companies, A and B, as well as to give the interviewees the freedom to share any ideas about how to improve maintenance. The main idea of the first interview was to identify key challenges related to maintenance work. The informants were asked about typical challenges emerging in the case company operations, not in any specific project. We selected companies due to their long history of development, profound access to data and direct informant contacts. Both companies were good representatives in their roles during building life cycle. Company A, a typical main contractor for buildings, having extensive experience operating in different countries. Company B, an international company, focussing more on facility management and maintenance.

Thematic interview analysis (Braun and Clarke, 2006) was used in the first round of interviews with both companies. This started with becoming familiar with all the data and reading the interview transcripts and notes twice. At the same time, initial codes for challenges in the maintenance phase were written down. In the second part of the analysis, codes for all the different challenges found in the interviews were generated. In third phase, the research team searched for common areas for the codes across the interviews in the two companies. Each code was written as a sticky note to improve the process and ease the creation of the overview. In the fourth phase of the analysis, main areas and sub-areas were created, reviewed and refined to ensure clear coherence inside each of the areas and to clearly differentiate between them. In the following phase, areas and their names were defined with details.

Company A was chosen for the second interview round because it is working with life cycle projects, whereas Company B has more knowledge on other construction project types. In the second interview round, the key challenges and challenge categories from the first interview round were used with MCC process elements found in the literature review to identify the most important requirements and activities during the design and construction phases of the construction project. The new interview set-up supported

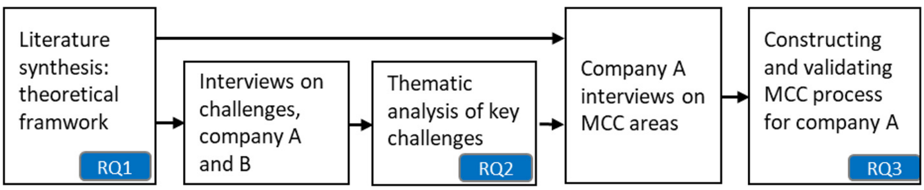

Figure 1. The research process of this study

Company A representatives in understanding and verifying the key MCC elements from the literature and analyse related key challenges. All the key requirements and activities that emerged from the second interviews were categorised as MCC areas, and in the final phase of the MCC process creation, these requirements and activities were divided into project stages. Finally, the MCC process proposal was validated with five key representatives of Company A.

Case company A is large international company in the architecture, engineering and construction sector. Six experienced key members of management and positions working with the life cycle project maintenance phase were interviewed (area director, real estate area manager, design director of the life cycle projects, property manager of the maintenance phase, manager of virtual design coordination and BIM coordinator). Both interview rounds were conducted online with two researchers, and both rounds lasted roughly two hours. The interviewees took notes, and all the interviews were recorded for more detailed analysis. All the interviewees from Company A reflected their opinions on six big ongoing or recently completed life cycle projects, which are currently in the maintenance phase; hence, the informants had relatively good experience with life cycle projects. The company was responsible for the design, construction and maintenance of all six projects, with a design–build agreement and maintenance responsibility for 20–25 years depending on the project.

Case company B is a large international company specialised in designing buildings, maintaining building systems and offering industrial services. A total of 12 experienced representatives of the company were interviewed, including relevant key personnel involved in building maintenance activities. Some of the interviewees represented business partners working with Company B. The roles of the participants included a design automation designer, design project development manager, facility maintenance management service manager, remote management specialist, two estate management technical managers, three facility maintenance service technicians, head of sales, development manager and innovations and development department manager. All informants have very long experience in maintenance-related challenges. A total of 11 interviews were conducted online and 1 face to face, with the interviews lasting roughly two hours each. The answers were not related to any specific project but associated with all the cumulative knowledge affiliated with the maintenance phase of construction projects.

4. Results

4.1 Key challenges

First interview round covered all the main areas associated with maintenance, including the processes companies are using in the design, construction and maintenance phases. Questions about information systems, data management processes and data ownership and governance were also asked. However, the key questions were aimed to find challenges affecting the maintenance phase of construction projects. Without underestimating the importance of more traditional elements of maintenance, the role of data and data management was found to be critical in thematic analysis (Figure 2).

The first main challenge is that the maintenance phase is not acknowledged during the design phase. Maintenance people are little involved in earlier phases of the construction project. There are several reasons for this. A designer in Company B defined one part of the problem:

> Maintenance stakeholder participation in the design process is very weak. We do send invitations to the planning meetings, but they are not participating actively. They might sometimes attend, but they don't really have a picture of the overall development process.

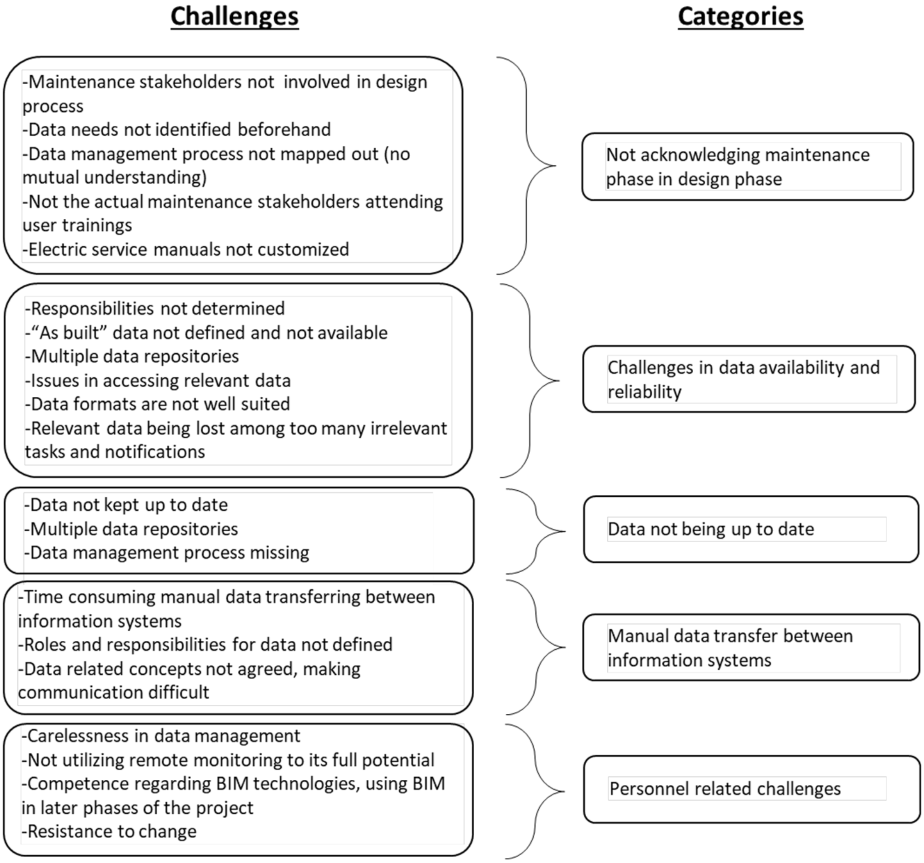

Figure 2.
Depicted challenges in the analysis of maintenance activities in the case companies

One root cause of this problem is that maintenance requirements are not clear to the involved stakeholders. A technical manager from Company B described this issue:

> I feel that we don't have a common understanding of data management process and principles in facility maintenance. We just get what the designers give to us. Normally, they haven't thought it out either.

The BIM coordinator of the Company A shared a similar opinion:

> The biggest problem from BIM point of view in maintenance work is, that we do not know, what maintenance phase people need", and" I do see as a big issue, that maintenance targets and actions how to achieve those should be opened and understood [. . .] and then move these actions to the start of the design phase.

Data needs of the maintenance phase have not been identified during the design phase because there are no processes or practices available for that purpose. Indeed, not only processes but also meeting agendas and tasks are not organised in the efficient way, making cultural change difficult. A real estate technical manager from company B described this issue:

> I do attend to some design meetings, but they are often quite tough and not so tangible. I do not feel it as very productive use of my time, as I am mostly an observer in the meetings.

Currently, electric service manuals are playing a key role in the maintenance phase. However, they are not customised to the needs in the design and construction phases. Sometimes even old service manuals are just updated quickly for the use of the maintenance personnel. The most common issue is that unnecessary maintenance tasks are included in the service manual, as noted by a real estate technical manager from Company B:

> The worst I have seen in the service manual has been the instructions related to maintenance of a swimming pool [. . .] there was no swimming pool in the entire facility.

The second, third and fourth main challenges are associated with a lack of product data management principles, which is causing technical challenges in data availability and reliability. This starts with ownership and governance and includes responsibilities for the activities. A technical manager of Company B discussed some of these challenges:

> The data management process in facility maintenance should be planned and mapped out. The earlier this is done, the better. Today, there is no mutual understanding of how and where the documents should be created, managed and updated. This is very confusing.

One of the biggest challenges for both companies is that data are separated into many data systems, and the data transfer does not work as it should. One reason for this could be that the format of the data is different in different tools. For example, in Company B, there are 17 data systems used in facility maintenance in addition to the normal office tools. Data transfer does not always work, as it should, as observed by a service manager from Company B:

> Sometimes data transmission works well and sometimes everything goes as wrong as it possibly can.

A remote monitoring specialist from company B added another dimension to the same problem:

> The main issue in data management in remote monitoring is that the information does not reach the specialists. Original designs and drawings are lost in the process. We do not have electric drawings of most of the facilities. Without the designs it is only guessing, how the designers have planned the automation to work. We need to use our competence and experience to assess whether the automation is working as it was designed to work.

There is a lot of time-consuming manual data transfer between information systems. It would be best if all the information needed for maintenance was in the same location or even linked properly to one location. As the BIM coordinator from Company A described:

> BIM should have a place for the information. If BIM would get new info, there would be enough to have the link to another system, which then could include more detailed information on for example maintenance timings and spare parts and so on. It might not be wise to insert everything in the BIM.

There can be issues in accessing the relevant data or issues related to functionalities. Relevant data can be lost when a tool manages and sends, for example, too many irrelevant notifications. In general, data are not kept up to date due to the abovementioned system-associated reasons and other problems in processes or related responsibilities.

The fifth main category of challenges is related to maintenance personnel. Tools are not used to their full potential, and there might not be sufficient competence to use all the available technologies. There is also carelessness evident in data management. A service manager from Company B gave an example of this type of problem:

> Someone has inserted the device data into the service manual and each year I've been trying to update the data, but it is too difficult [. . .] I have 150 destinations in the area, operated by different stakeholders. All the changes are difficult to keep track of. Sometimes the information in the service manual is so contradictory that I'm afraid to update it, I do not want to cause any problems with my updates.

From the management point of view, practices have not been put in place. The area manager of facility maintenance for Company A described this situation:

> We have a gap in our way of work in the facility maintenance, it is not systematically lead with the KPIs [key performance indicators]. Now we do report certain KPIs, but only for the customer. We should measure more and analyse the metrics, have internal targets in facility maintenance and so on. In practice we would have KPIs and systems to report these quite well in place.

The same problem can be seen when actual maintenance stakeholders are not attending user trainings during the construction phase, as noted by a real estate technical manager from Company B:

> The contractors don't really care who and how they train, as long as they get approval of the trainings done and they can then move on to next projects. And I do understand it, maintenance is not their responsible area.

A final issue raised by many of the interviewees is resistance to change, which hinders trainings, enacting new processes and fulfilling the potential of the available resources.

4.2 Maintenance capability creation process

The generic manufacturing and electronics industry literature provides CC processes for improving later phases of the product life cycle (Tolonen *et al.*, 2017; Verrollot *et al.*, 2017; Annunen *et al.*, 2021). Analogously, we adopted a generic MCC process for the building life cycle (Figure 3).

For the generic process, we organised the second data collection (interviews) in Company A to enable more detailed knowledge of MCC elements. Company A has relatively good experience with life cycle projects (DBOOT) for buildings and is also planning similar activities to our MCC process. Based on maintenance elements described in the literature and challenges from Companies A and B, we collected typical requirements and activities in the design and construction phases that are critical for maintenance phase. The results from the analysis of the second interview round are summarised in Table 1, which presents all the MCC process areas and elements, along with associated key requirements and activities in the design and construction phases. Based on the practical requirements and activities in the design and construction phases found in the literature, we also classified MCC elements into more generic MCC areas.

The service and maintenance main area covers five different sub-areas. The aim of this main area is to define the requirements and build the capabilities of most technical maintenance areas.

In the quality main area, the target is to design and ensure the quality requirements and systematic quality control practices for the maintenance phase, including the auditing process and systematic practices to ensure customer satisfaction. The foundation for this is based on systematic control of the maintenance service quality.

The target of data and product area is to ensure that maintenance will have correct data and that the data enable efficient maintenance practices. Information must be up to date, in

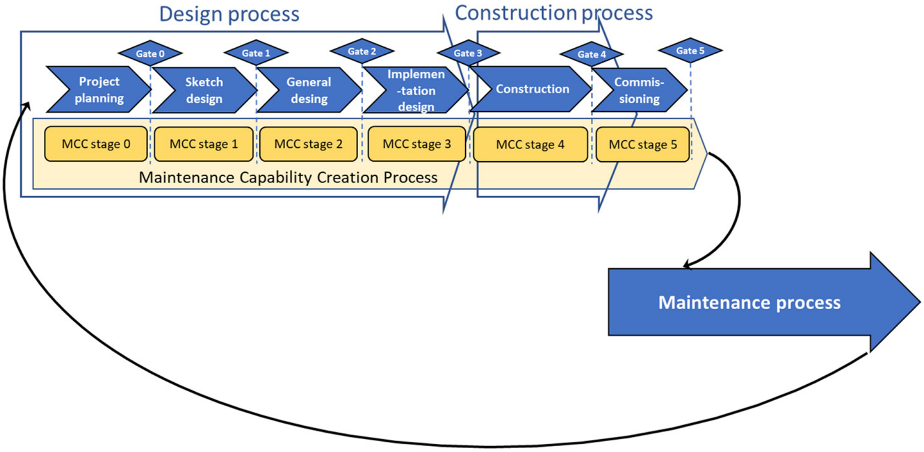

Figure 3.
Generic MCC process concurrent to design and construction processes

Notes: The maintenance process informs requirements for the design and construction processes, and the MCC process creates capabilities for the maintenance process

the correct location, in the correct format and usable by the parties needing the data. A standardised product data structure and BIM design are essential. Additionally, data and product management processes need to be in place as a precondition for this main area. The aim of the project management area is to involve all the necessary stakeholders and ensure the proper competencies and resources for the maintenance phase. Management of the whole MCC project belongs in this area, including important cost management activities.

These requirements and activities are difficult to achieve without a systematic CC process with pre-planned actions for each stage and gate. From a practical perspective, it is critical to note that maintenance must be the responsible stakeholder who implements the MCC process, not the design or construction. Maintenance personnel have the best possible competence to organise maintenance – concurrent to the design and construction phases, not in the maintenance phase. Table 1 lists the requirements and activities in detail. At a generic level, the contents of these 12 elements would require more extensive descriptions for each stage in the construction project (Figure 4). However, depending on the case, it is more important to describe these in a case-specific manner. In fact, processing the 12 capability elements in a project-specific manner would be highly beneficial in a real-life project.

The pre-requisites for the MCC process are definitions of the main processes, that is, the design, construction and maintenance processes, including the process owners. The review process for gates needs to be defined with governance and related details, including the participants and agenda for each gate (0–5) review. The tasks in each stage for each gate review need to be agreed upon (Cooper, 2011; Ulrich and Eppinger, 2008). Additionally, personnel competencies must be in place for the new way of work, with necessary trainings. A global MCC process owner must be appointed to manage the process development and content, managing the process with KPIs and gathering feedback continuously.

Each construction project requires an MCC project manager, who oversees the management of the proposed process throughout all the project phases. The MCC project manager is part of the project management team, serving as a maintenance representative and enhancing life cycle aspect considerations in decision-making during the project. In the current organisational set-up in Company A, a maintenance or real estate manager will

MCC Area	MCC element	Key requirements and activities in the design and construction Phases
I. Service and maintenance	1. Real estate maintenance	Choose and involve service partners. Create the needed practices and foundation for successful technical services, real estate maintenance, cleaning services and maintenance of outdoor areas. Select necessary tools, building elements and materials from a maintenance point of view. Take care of device and system requirements of the maintenance phase
	2. Energy management services	Choose and involve energy management service partner. Ensure proper energy usage and energy-efficient target setting, simulations and tests during the design phase and achievement of the targets for the maintenance phase. Notice and create energy consumption, follow-up and savings-related capabilities
	3. Facility and user services	Plan and ensure maintenance phase readiness according to requirements for the office, lobby, canteen, security, IT, user and other employee services. Choose and involve required service partners
	4. Building management plan and maintenance manual	Start the creation of a building management plan and the electrical service book at the beginning of the project. Choose and involve the BM service partner. Define the correct contents of the BMP and maintenance manual during the design and construction phases. Ensure the correct IT systems and necessary instructions to use and maintain BMP and the maintenance manual during the maintenance phase
	5. Sourcing and logistics	Note sourcing and logistics requirements and ensure seamless functioning of these in the maintenance phase. Ensure that the required equipment (e.g. spare parts) is available in the correct place on the required schedule. Agree on suppliers, required materials and define the logistics process for main supplies in the maintenance phase. Ensure the availability of the most critical materials for the whole maintenance phase. Prepare and agree on contracts with the key suppliers and service providers
II. Quality	6. Quality management	Define and implement quality requirements for service partners and stakeholders with agreed responsibilities (operative management, cleaning services, outdoor area maintenance). Define quality follow-up and testing practices and schedule for the maintenance phase. Implement customer satisfaction measurements and auditing practices
	7. Reporting and coordination	Ensure the capability to follow-up on maintenance phase service and quality for both personnel and data systems. Build reporting and control systems for maintenance
III. Data and product	8. Data management	Create instructions, practices and governance to ensure good data management capabilities during the design, construction and maintenance phases. Create capabilities to utilise, create, store, update and archive the data efficiently with the data management systems. Define communication channels and the data transfer policy. Implement a centralised PDM system, including responsibilities. Harmonise data updates and software interfaces with as much automation as possible

(*continued*)

Table 1. 4 MCC areas and 12 MCC elements, with associated key requirements and activities

MCC Area	MCC element	Key requirements and activities in the design and construction Phases
	9. Product management	Specify instructions to create a product structure to ensure maintenance requirements for the building. Define product data and data for maintenance phase business process. Address product data requirements for earlier phases and data creators in the design process. Define and ensure the instructions, practices and governance of the product data for the maintenance phase, including change management and updates
IV. Project management	10. Training	Ensure maintenance personnel and user trainings and introductions before the maintenance phase. Prepare the necessary documentation, training materials and practices. Ensure resources (with work amount estimates) and their competencies to perform the required maintenance tasks
	11. Collaboration	Involve users and maintenance personnel in the design phase. Ensure requirement integration with stakeholders in the design process, including required practices and methods, such as big room and last planner. Plan and create the capabilities for collaboration in the maintenance phase, including contact lists
	12. MCC project management	Lead the MCC project based on a detailed stage-specific project plan and report the status in each gate in the project design and construction phases. This area includes required general project management activities, such as cost, document and requirement management. This part also includes other tasks, such as insurance for service providers

Note: IT = Information technology

Table 1.

assume the MCC project manager role depending on the project. In larger projects, some MCC areas or MCC elements can be led by an individual reporting to the MCC project manager.

The MCC process was validated by five experts in Company A. Two of the experts were the same as in the interviews (real estate area manager and BIM coordinator), whereas others participating in the validation session included the director of life cycle projects, the vice president of strategy and development and the director of property and facilities management. Validation was conducted in one session, where the MCC process was described without any commenting, and 10 different questions were evaluated individually on a scale ranging from 1 to 5 (1 = very poor; 5 = really good). In addition, there was a discussion after grading on the positive and negative aspects of the proposed MCC process. In particular, the relevance (4,0), usability (4,2) and practicability (3,7) of the MCC process were valued in the validation. Likewise, implementing new practices for data management and requirement management to enable efficient MCC usage was seen positively (3,6). On the other hand, some development items were listed for the future, including clarifications of the PDM and PLM concepts and the maintenance vocabulary overall. The average score for all ten questions in validation was 3,8. As management summary, the transparency of the systematic MCC process was seen as a major improvement to the old way of working. Further, support is needed in the implementation of the MCC process from the start of next life cycle project. In the end, the decision to

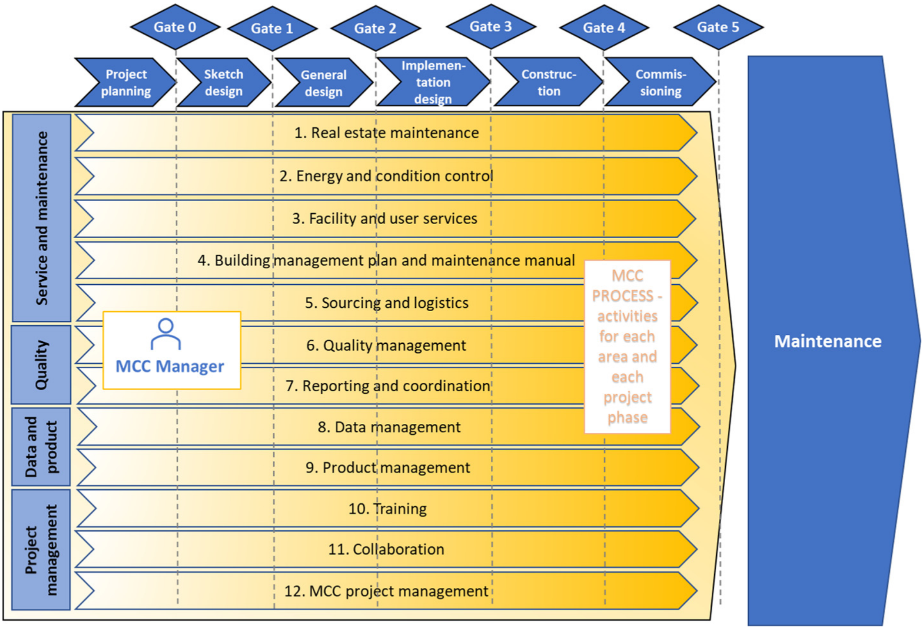

Figure 4.
MCC process phases and structure increase the level of detail in maintenance plans and capabilities throughout the evolution of the design and construction process

enact the MCC process to use was made by the area director of the Company A, and the decision was supported by all participants in validation.

4.3 Discussion

The scientific contribution of this study is related to the potential of the MCC process with four main areas and 12 elements, complementing the current literature by describing the current status of maintenance work in real companies. These elements were originally rooted from literature and more specifically validated and defined trough the empirical material in this study. The study supports the current view on maintenance phase problems (Waziri, 2016; Gao and Pishdad-Bozorgi, 2019; Hassanain *et al.*, 2019; Sulaiman *et al.*, 2021; Hauashdh *et al.*, 2022) as well as the importance of the maintenance phase (Heaton *et al.*, 2019; Harkonen *et al.*, 2019; Halttula *et al.*, 2020). The results highlight the concentration on processes (Eastman, 2008; Dave, 2017; Halttula *et al.*, 2020) and governance of the processes (i.e. MCC process owner) (Silvola *et al.*, 2019) in construction. Importantly, the study proposes a method to involve maintenance concretely in earlier phases of the project (Ganisen *et al.*, 2015), establishing the design requirements. The proposed CC process complements the research in other business areas and industries (Tolonen *et al.*, 2017; Verrollot *et al.*, 2017; Annunen *et al.*, 2021) and highlights the importance of creating maintenance phase capabilities (Isoherranen and Majava, 2018) in the project design and construction phases (Love *et al.*, 2004; Aapaoja and Haapasalo, 2014; Islam *et al.*, 2021; Weeks and Leite, 2021). The study confirms the need to have a systematic stage-gate process in place to support an efficient project design phase (Ulrich and Eppinger, 2008; Cooper, 2011), but it also offers a new perspective on using it in the construction industry.

In this study, the validated four MCC main areas and 12 elements can be generalised not only as baseline for further studies but also as generic elements of the MCC process. These elements were piloted in the study with large main contractor for buildings (Company A), having wide experience operating in different countries. We described the more detailed content for these 12 elements as activities along the 6 stages of the MCC process resulting in total 72 sections of activities for Company A. These 72 sections are case or building object specific and cannot be generalised, and therefore are not presented in this study. The main purpose of the MCC process is to ensure, that these 12 elements are systematically considered and used to specify the detailed activities in the case specific projects, MCC process operating as a platform for the agreed activities.

Therefore, the managerial contributions of this study include presenting an MCC process to support companies in planning their maintenance-related capabilities. This study provides information regarding the pre-requisites and detailed steps for building these capabilities during the design and construction phases, facilitating a smooth commissioning phase and, ultimately, a successful maintenance phase. Further, the study shows how processes should be managed in conjunction with business processes and how a systematic stage-gate model supports the targets of improved quality and decreased life cycle costs.

Current challenges of the maintenance phase could be managed with the proposed MCC process by involving the maintenance personnel earlier and managing the requirements systematically in the front end of the construction project. Systematic management of the maintenance challenges in the front end of the project will result improved data quality for the whole building life cycle, easier data transfer and utilization, especially in the maintenance phase, and finally, with improved design of the building itself (Halttula *et al.*, 2017; Halttula *et al.*, 2020). Ultimately, MCC process will enable lower life cycle cost for the object (Tolonen *et al.*, 2017).

5. Conclusions

According to previous studies, cooperation between construction project phases or stakeholders has been challenging. Earlier studies suggest that the design and construction phases cause problems for the maintenance phase, especially in the event of poor data management, which creates further problems in several other areas. Systematic processes can support cooperation and enable development of the whole construction industry. However, the methods for building maintenance phase capabilities in earlier project phases have not been adequately described in the previous literature. Hence, this study describes and validates an MCC process as a potential solution to these problems.

The literature indicates 12 key elements that must be managed during the whole construction project, related to service and maintenance, quality, product, data and project management. The current challenges in maintenance are various, starting with not considering the maintenance phase in the design phase. There are challenges in data availability and reliability, data not being up to date and in manual data transfer between information systems. Personnel-related challenges exist as well, including carelessness, missing competencies and resistance to change. Our study found 12 relevant MCC elements and provides insight on how to address these in the design and construction phases.

The results indicate that the MCC process could provide a solution to the presented challenges. Key requirements and activities of the MCC process were listed, and they were further divided into six stages of the design and construction process, with respective management practices for validation. Governance and owners also agreed to support the process.

The limitations of this study include the small number of analysed companies, although both companies are large players in the construction maintenance area, and the interviewees had broad experience. The process was validated for use in Company A, but real-life testing remains for future studies. The use of the MCC process in other types of projects and in smaller projects requires further studies to finetune the process for the context. While the validation was performed with large life cycle projects, the main principles of the process should apply to any kind of construction environment. It would also be interesting to test the MCC process in infrastructure projects.

References

Aapaoja, A. and Haapasalo, H. (2014), "A framework for stakeholder identification and classification in construction project", *Open Journal of Business and Management*, Vol. 02 No. 01, pp. 43-55.

Annunen, P., Mustonen, E., Harkonen, J. and Haapasalo, H. (2021), "Sales capability creation during new product development – early involvement of sales", *Journal of Business and Industrial Marketing*, Vol. 36 No. 13, pp. 263-273.

Boton, C., Rivest, L., Forgues, D. and Jupp, J. (2016), "Comparing PLM and BIM from the product structure standpoint", in Harik, R., Rivest, L., Bernard, A., Eynard, B. and Bouras, A. (Eds), *Product Lifecycle Management for Digital Transformation of Industries. PLM 2016. IFIP Advances in Information and Communication Technology*, Springer, Cham, Vol. 492.

Braun, V. and Clarke, V. (2006), "Using thematic analysis in psychology", *Qualitative Research in Psychology*, Vol. 3 No. 2, pp. 77-101.

Bryman, A. and Bell, E. (2011), *Business Research Methods*, 3rd ed., Oxford University Press, Oxford.

Cooper, R.G. (2011), *Winning at New Products: Creating Value Through Innovation*, 4th ed., Basic Books, New York, NY.

Crnkovic, I., Asklund, U., Persson., and Dahlqvist, A. (2003), *Implementing and Integrating Product Data Management and Software Configuration Management*, Artech House Inc., Norwood, MA.

Dahanayake, K.C. and Sumanarathna, N. (2022), "IoT-BIM-based digital transformation in facilities management: a conceptual model", *Journal of Facilities Management*, Vol. 20 No. 3, pp. 437-451.

Dave, B. (2017), "Business process management – a construction case study", *Construction Innovation*, Vol. 17 No. 1, pp. 50-67.

De Silva, N., Ranasinghe, M. and De Silva, C.R. (2012), "Maintainability approach for lean maintenance", in Senaratne S. and Sandanayake Y.G. (Eds), *Global Challenges in Construction Industry*, Ceylon Institute of Builders, Colombo, pp. 100-109.

Eastman, C.M., Eastman, C., Teicholz, P., Sacks, R. and Liston, K. (2008), *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors*, Wiley, New York, NY.

Ebekozien, A. (2021), "Maintenance practices in Nigeria's public health-care buildings: a systematic review of issues and feasible solutions", *Journal of Facilities Management*, Vol. 19 No. 1, pp. 32-52.

Ebekozien, A., Dominic Duru, O.S. and Dako, O.E. (2022), "Maintenance of public hospital buildings in Nigeria – an assessment of current practices and policy options", *Journal of Facilities Management*, Vol. 20 No. 1, pp. 120-143.

Ganisen, S., Mohammad, I.S., Nesan, L.J., Mohammed, A.H. and Kanniyapan, G. (2015), "The identification of design for maintainability imperatives to achieve cost effective building maintenance: a Delphi study", *Jurnal Teknologi*, Vol. 77 No. 30.

Gao, X. and Pishdad-Bozorgi, P. (2019), "BIM-enabled facilities operation and maintenance: a review", *Advanced Engineering Informatics*, Vol. 39, pp. 227-247.

Giménez, D.M., Vegetti, M., Leone, H.P. and Henning, G.P. (2008), "Product ontology: defining product-related concepts for logistics planning activities", *Computers in Industry*, Vol. 59 Nos 2/3, pp. 231-241.

Halttula, H., Haapasalo, H. and Silvola, R. (2020), "Managing data flows in infrastructure projects – the lifecycle process model", *Journal of Information Technology in Construction*, Vol. 25, pp. 193-211.

Halttula, H., Haapasalo, H., Aapaoja, A. and Manninen, S. (2017), "Early involvement and integration in construction projects: the benefits of DfX in elimination of wastes", *International Journal of Management, Knowledge and Learning*, Vol. 6 No. 2, pp. 215-237.

Harkonen, J., Mustonen, E. and Haapasalo, H. (2019), "Construction related data management – classification and description of data from different perspectives", *International Journal of Management, Knowledge and Learning*, Vol. 8 No. 2, pp. 195-220.

Hassanain, M.A., Al-Zahrani, M., Abdallah, A. and Sayed, A.M. (2019), "Assessment of factors affecting maintenance cost of public-school facilities", *International Journal of Building Pathology and Adaptation*, Vol. 37 No. 5, pp. 528-546.

Hauashdh, A., Jailani, J., Abdul Rahman, I. and Al-Fadhali, N. (2022), "Factors affecting the number of building defects and the approaches to reduce their negative impacts in Malaysian public universities' buildings", *Journal of Facilities Management*, Vol. 20 No. 2, pp. 145-171.

Heaton, J., Parlikad, A.K. and Schooling, J. (2019), "Design and development of BIM models to support operations and maintenance", *Computers in Industry*, Vol. 111, pp. 172-186.

Hietajärvi, A.M. and Aaltonen, K. (2018), "The formation of a collaborative project identity in an infrastructure alliance project", *Construction Management and Economics*, Vol. 36 No. 1, pp. 1-21.

Islam, R., Nazifa, T.H., Mohammed, S.F., Zishan, M.A., Yusof, Z.M. and Mong, S.G. (2021), " "Impacts of design deficiencies on maintenance cost of high-rise residential buildings and mitigation measures", *Journal of Building Engineering*, Vol. 39.

Isoherranen, V. and Majava, J. (2018), "Customer care excellence in the new product development process: a case study", *International Journal of Value Chain Management*, Vol. 9 No. 1, pp. 26-37.

Jupp, J.R. (2013), "Incomplete BIM implementation: exploring challenges and the role of product lifecycle management functions", in Bernard, A., Rivest, L. and Dutta, D. (Eds), *Product Lifecycle Management for Society. PLM 2013. IFIP Advances in Information and Communication Technology*, Springer, Berlin, Heidelberg, Vol. 40.

Kerosuo, H., Miettinen, R., Mäki, T., Paavola, S., Korpela, J. and Rantala, T. (2012), "Expanding uses of building information modeling in life-cycle construction projects", paper presented at IEA 2012: 18th World Congress on Ergonomics – Designing a Sustainable Future, 1 January, pp. 114-119.

Kess, P. and Haapasalo, H. (2002), "Knowledge creation through a review practice in software development project – a case from telecom industry", *International Journal of Production Economics*, Vol. 80 No. 1, pp. 49-55.

KH X9-00526 (2013), *Kiinteistöliiketoiminnan Sanasto (Real Estate Business Vocabulary) (in Finnish), Finnish National Property Management File*, 2nd ed, Rakennustieto Oy, Helsinki.

KH 90–00612 (2016), *Kiinteistönpitokirja. Uudisrakennukset ja Rakennukset (Facility Mangement Handbook for Buildings) (in Finnish), Finnish National Property Management File*, Rakennustieto Oy, Helsinki.

Lavy, S. and Jawadekar, S. (2014), "A case study of using BIM and COBie for facility management", *International Journal of Facility Management*, Vol. 5 No. 2.

Love, P.E.D., Irani, Z. and Edwards, D.J. (2004), "A seamless supply chain management model for construction", *Supply Chain Management: An International Journal*, Vol. 9 No. 1, pp. 43-56.

Mansoori, S., Haapasalo, H. and Harkonen, J. (2022), "Potential of building information modeling in the project lifecycle – reflection against iceberg model", *International Journal of Management, Knowledge and Learning*, Vol. 11.

Pirinen, A. and Kukkonen, E. (2001), *Rakennuksen Huoltokirjan Laadinta ja HyöDyntäMinen (Creation and Use of the Building Maintenance Manual) (in Finnish)*, Rakennustieto Oy, Helsinki.

RT 103166 (2020), *Elinkaarihankkeen Palvelusopimuksen Laatiminen (Service Agreement for Life-Cycle Contract) (in Finnish), Finnish National Building Information File*, Rakennustieto Oy, Helsinki.

RT 18-10922 (2008), *Künteistön Tekniset Käyttöiät ja Kunnossapitojaksot (Technical Life-Time and Maintenance Periods for Facilities) (in Finnish), Finnish National Building Information File*, Rakennustieto Oy, Helsinki.

Saaksvuori, A. and Immonen, A. (2008), *Product Lifecycle Management Systems*, Springer, Berlin, Heidelberg.

Silvola, R., Tolonen, A., Harkonen, J., Haapasalo, H. and Männistö, T. (2019), "Defining one product data for a product", *International Journal of Business Information Systems*, Vol. 30 No. 4, pp. 489-520.

Stark, J. (2015), *Product Lifecycle Management – 21st Century Paradigm for Product Realisation*, Springer, New York, NY, Vol. 1, pp. 105-201.

Sulaiman, M., Sulaiman, M., Liu, H., Binalhaj, M., Al-Kasasbeh, M. and Abudayyeh, O. (2021), "ICT – based integrated framework for smart facility management: an industry perspective", *Journal of Facilities Management*, Vol. 19 No. 5, pp. 652-680.

Tampio, K.-P. and Haapasalo, H. (2022), "Organizing methods enabling integration for value creation in complex projects", *Construction Innovation*.

Tampio, K.-P., Haapasalo, H. and Ali, F. (2022), "Stakeholder analysis and landscape in a hospital project – elements and implications on value creation", *International Journal of Managing Projects in Business*, Vol. 15 No. 8, pp. 48-76.

Tolonen, A., Haapasalo, H., Harkonen, J. and Verrollot, J. (2017), "Supply chain capability creation – the creation of the supply chain readiness for a new product during product development process", *International Journal of Production Economics*, Vol. 194, pp. 237-245.

Ulrich, K.T. and Eppinger, S.T. (2008), *Product Design and Development*, 4th ed., International edition, McGraw-Hill, Boston.

Verrollot, J., Tolonen, A., Harkonen, J. and Haapasalo, H. (2017), "Supply capability creation process: key milestone criteria and activities", *Journal of Industrial Engineering and Management*, Vol. 10 No. 3, pp. 495-521.

Waziri, B.S. (2016), "Design and construction defects influencing residential building maintenance in Nigeria", *Jordan Journal of Civil Engineering*, Vol. 10 No. 3.

Weeks, D.J. and Leite, F. (2021), "Facility defect and cost reduction by incorporating maintainability knowledge transfer using maintenance management system data", *Journal of Performance of Constructed Facilities*, Vol. 35 No. 2.

Appendix

MCC element	Sub-elements	References
1. Real estate maintenance	Technical services, maintenance operations, cleaning services and maintenance of outdoor areas	KH X9-00526 (2013) RT 103166 (2020) Isoherranen and Majava (2018)
2. Energy management services	Simulations and tests. Consumption, follow-up and energy savings	KH X9-00526 (2013) RT 103166 (2020)
3. Facility and user services	Office, lobby, canteen, security, IT, user and employee services	KH X9-00526 (2013) RT 103166 (2020)
4. Building management plan and maintenance manual	–	Pirinen and Kukkonen (2001) RT 18-10922 (2008) RT 103166 (2020) Isoherranen and Majava (2018)
5. Sourcing and logistics	Materials and logistics process. Critical material availability. Key suppliers and service providers	Tolonen *et al.* (2017) Isoherranen and Majava (2018)
6. Quality management	Quality requirements of operative management, cleaning services, outdoor area maintenance. Requirements for service partners and other stakeholders	RT 103166 (2020) Verrollot *et al.* (2017)
7. Reporting and coordination	Service and quality reporting. Personnel and data systems in maintenance	Annunen *et al.* (2021) Gao and Pishdad-Bozorgi (2019) RT 103166 (2020)
8. Data management	Data management process including utilisation, creation, storing, updating and archiving the data. Communication channels and data transfer policy. Centralised data management, data interfaces	Silvola *et al.* (2019) Halttula *et al.* (2020) Mansoori *et al.* (2022) Jupp (2013) Boton *et al.* (2016) KH 90–00612 (2016)
9. Product management	Product structure, product data, product management process. Governance and ownership of the product data. Change management	Silvola *et al.* (2019) Halttula *et al.* (2020) Mansoori *et al.* (2022) Jupp (2013) Boton *et al.* (2016) Harkonen *et al.* (2019)
10. Training	Required documentation, training materials and practices. Resources and their capabilities for maintenance	Annunen *et al.* (2021) Verrollot *et al.* (2017) Lavy and Jawadekar (2014)
11. Collaboration	Early involvement, personnel collaboration, requirement integration	Halttula *et al.* (2020) Hietajärvi and Aaltonen (2018)
12. MCC project management	Project planning and reporting. Cost management, document management and requirement management. Customer satisfaction	RT 103166 (2020) Isoherranen and Majava (2018) Tolonen *et al.* (2017)

Table A1.
Literature review on required elements for facility maintenance

Corresponding author
Harri Haapasalo can be contacted at: harri.haapasalo@oulu.fi