The role of purchasing in raising the maturity of smart maintenance management

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Abstract

Purpose –
The aim of this study is to provide insights into how the purchasing function can increase the maturity of smart maintenance management (SMM) in construction clients by 1) assessing current SMM maturity and 2) developing an adapted service triad for purchasing's meaningful involvement in SMM.

Design/methodology/approach –
A multiple case research design was used, and data were collected from four higher education institutes in the Netherlands through an assessment of their current SMM maturity. Coding and a cross-case analysis were used to qualitatively analyze the data to identify roles and value chain integration factors as intermediate steps in adapting the service triad to a service hexad.

Findings –
Within construction client organizations, collaboration between maintenance management, project management, and ICT services requires improvement. The proposed service hexad redefines the client's SMM roles with the aim of improving collaboration. We discuss how this enables a transition to higher levels of SMM maturity.

Practical implications –
Implementing the service hexad provides construction clients with a stronger position in supply networks. It clarifies the briefing process in construction management and emphasizes the data supply responsibilities of construction management professionals.

Research limitations –
The findings were derived from a particular class of construction clients: higher education institutes that operate owner-occupied properties. Although the service hexad could be adapted, to owner-occupied multi-user properties, further research is necessary to assess its relevance for investor-owned properties.

Originality –
The study draws on the service triads and meaningful involvement concepts from the purchasing literature and applies them to SMM.

Keywords: construction clients, asset management, facilities management, real estate, maturity assessment, multiple case study, service triads, collaboration

Article classification: Research paper

Introduction

Given the substantial costs of building maintenance, purchasing departments of construction clients have sought to get involved in purchasing maintenance services. However, this has been complicated because technical departments see themselves as responsible for at least part of the definition, procurement, and delivery of maintenance services (Van Weele, 2014; Ueltschy Murfield *et al*., 2021). Furthermore, the transition to smart maintenance management (SMM) introduces additional challenges. A typical example of a SMM application is the use of sensors, the internet of things, and artificial intelligence techniques to monitor an asset's condition and predict the timing of failures. While this enables a more effective and efficient servicing of elevators, chillers and similar equipment, it also increases the institutional complexity of maintenance because the data, in part, has to come from assets that are installed during earlier construction stages. The institutional complexity of SMM addressed in this paper refers to the interplay and concurrent presence of the logics both of new construction and of maintenance that impose incompatible demands on the construction client (Greenwood *et al.,* 2011).

The smart maintenance literature has sought to understand the impact on organizations of using advanced technologies, data science, and predictive analytics (e.g., Lee *et al*., 2014; Bokrantz *et al*., 2020), but has not been able to explain how the transition toward smart maintenance affects the role of purchasing in institutionally complex construction clients.

In response, the aim of this study is to provide insights into how purchasing can increase SMM maturity in construction clients by 1) assessing current SMM maturity and 2) developing an adapted service triad for the meaningful involvement of purchasing in SMM. We define smart maintenance management (SMM) as the process of directing, controlling, and monitoring the supply and delivery of the services that constitute smart maintenance.

This paper addresses the following research question: What determines the role of purchasing in raising maturity levels of SMM in institutionally complex environments? To answer this question, an adapted service triad for SMM is developed that integrates different roles and describes the role of purchasing in that integration process. Purchasing in this study refers to the operational supply and delivery of smart maintenance services (Van Weele, 2014; Murray, 2009).

To empirically develop an adapted service triad, this study measures SMM maturity in higher education institutes as a particular class of construction clients. Intra- and inter-organizational relationships and data exchange are fundamental elements of SMM (Bokrantz *et al.,* 2020). As such, measuring current SMM maturity can generate insights into role interactions which can be used to adapt the classical service triad configuration used to model the interaction between buyer, supplier, and end-user (Wynstra *et al.,* 2015), and identify ways for purchasing to increase SMM maturity.

The following section reviews the relevant literature. The methodology section then describes how maturity assessments have been used in a multiple case study to adapt the service triad concept, increasing its relevance for SMM. Subsequently, the case study findings are presented and discussed. Based on the findings, we adapt the service triad to a service hexad for SMM and discuss three ways in which purchasing could increase SMM maturity. The closing section draws conclusions and makes suggestions for future research.

Literature review

The client's role in construction

The client's role in construction has received substantial attention from academics. Much of this research was fueled by discontent with the construction industry's performance and the perceived lack of innovation (Cherns and Bryant, 1984; Boyd and Chinyio, 2006). This has led to a stream of literature on the client's role in commissioning. In its commissioning role, the client makes decisions that affect downstream collaboration in the supply chain, and hence influences construction innovation (Bresnen and Marshall, 2000; Briscoe *et al.,* 2004). Another, more practice-oriented field of research relates to the client's briefing role in commissioning. Briefing is an early stage in the construction process during which a client's requirements are identified and communicated (Barret *et al.,* 1999). It is the process through which actors involved in designing and constructing of structural works are informed about the aspirations, desires and needs of the client. Poorly articulated client needs at the start of design, development and procurement processes will fail to deliver value because the actual needs were not identified and understood. Ideally, briefing is a cyclical process where, over time, all the involved actors can arrive at a shared meaning of values, beliefs, and client needs (Loosemore and Chandra, 2012). Recent research on the client's role in commissioning has recognized their responsibilities as custodians of values related to an asset's entire life cycle (Aliakbarlou *et al.,* 2017; Kuitert *et al.,* 2019) and called for clients to move beyond 'a lowest price' mentality (Loosemore and Richard, 2015).

Reflecting on the literature on the client's role in construction commissioning, we make three observations. First, most of the traditional literature views the commissioning of projects as a temporary phenomenon. While this is understandable from a construction industry perspective, given that a project-based delivery mode is the dominant business model, it is less obvious for clients who become the designated owner and operator of the asset. The ongoing process of adapting buildings to the changing end-user needs, requires a way to connect the project-based delivery mode with other service delivery modes for ongoing planned and corrective maintenance. Our second observation is that, in commissioning, a great deal of attention is given to the interactions between clients and external actors in the supply network: engineering consultants, designers, contractors, subcontractors, and suppliers. This plays down the roles of the different internal client interest groups involved. A third observation relates to the role of the purchasing function in construction clients. In the extant literature on procurement and purchasing in construction, the role of purchasing is investigated from a construction companies' perspective (e.g., Bemelmans et al., 2013). The focal point of these investigations is the purchasing relationship between the construction company and its suppliers. We found no study that investigates the purchasing function within the construction client itself.

This study aims to fill that gap by exploring the role of purchasing and other client interest groups. In the purchasing literature, the concepts of 'meaningful involvement' and 'service triads' relate to these challenges. While meaningful involvement is concerned with the value by purchasing in buying technical services, service triads describe the three-party collaboration between buyer, supplier, and end-user.

Meaningful involvement of purchasing

Meaningful involvement of the purchasing function in purchasing and in the supply of specialized complex services has been discussed by Schiele and McCue (2006), Johnson and Leenders (2003), Ellram and Tate (2015), and Holma *et al.* (2020). Johnson and Leenders (2003) distinguished four levels of involvement: from no involvement at all to documentary, professional, and meaningful involvement. While documentary involvement is limited to administrative activities (e.g., setting out requests for proposals and collecting offers on behalf of internal departments), professional involvement includes higher order activities. These can include meeting with internal departments to discuss needs and providing internal departments with unsolicited advice that can facilitate the purchasing process (Johnson and Leenders, 2003). Meaningful involvement is similar to professional involvement but goes further in considering the interrelatedness of various purchasing activities and their effects on the long-term needs and strategies of the construction client's organization as a whole. It is considered 'the ultimate state of perfection and integration with all other functions and activities in the organization' (Johnson and Leenders, 2003 p.38). For this study, we define the meaningful involvement of purchasing in SMM as the fulfilling of an intermediary role between the contractor and internal construction client units with the aim of increasing the construction client's overall SMM maturity. Holma *et al.* (2020) proposed a model for meaningful involvement in a triadic configuration with distinct roles for buyer, supplier, and end-users. This forms the theoretical starting point for this study and the associated service triads literature is briefly discussed below.

Service triads

When purchasing maintenance services and/or components, a contract is negotiated with suppliers that deliver their actual services to end-users (in this context: business units), thereby creating a service triad. Triads are three-party configurations of buyer, supplier, and end-user. While some of the literature on triads deals with product supply chains, most research has focused on service triads (e.g., Li and Choi, 2009; Li *et al.*, 2019). A study incorporating both product and service triads was conducted by Peng *et al.* (2010) who investigated thirteen triads involved in military avionics maintenance. Finne and Holmström (2013) discussed service triads among subsystem suppliers, system integrators, and end-users. Wynstra *et al.* (2015) presented an overview of the service triads literature. While a substantial part of the literature has investigated triads with actors from three different organizations, Anderson-Cederholm and Gyimóthy (2010) and Tate *et al.* (2010) discussed service triads where two of the three actors came from the same organization, and the study by Agneessens and Wittek (2012) on inter-personal knowledge sharing was focused on triads within a single organization. Triads perform critical functions in specifying services, and monitoring service quality and supplier performance (Van der Valk and Van Iwaarden, 2011; Holma *et al.,* 2020). Building on this, this paper discusses the outcomes of the maturity assessments from a service triads' perspective. Such a perspective takes both the external service supply network and the internal stakeholder network into account since SMM is situated at their interface (Dubois and Wynstra, 2005).

Methodology

Multiple case research design

The involvement of purchasing in SMM takes place in real life. Case studies are well suited to study such contemporary phenomena in real life empirical settings (Yin, 2014). The cases for our study were selected from a specific class of construction clients (higher education institutes or HEIs) for two reasons. First, HEIs are sufficiently large to meet the key selection criterion of institutional complexity. Having a separate purchasing function and multiple special client-interest groups, they constitute a relevant environment for conducting rich case studies into the construction client's role. The second reason for selecting HEIs was the desire to use an existing SMM maturity model that had been developed in another multiple case study using data from HEI cases (Anonymous, 2021). By duplicating the empirical context, it was straightforward to transfer the existing maturity model to this study. The maturity levels are operationalized in this model according to the six value chain integration stages discussed by Bemelmans *et al.* (2013) and clarified by Van Weele (2014, pp. 67-70). This approach offers a rich and informative assessment of SMM in a networked environment. Based on a content analysis, the six value chain integration stages of Van Weele's purchasing model (*transactional orientation, commercial orientation, maintenance coordination*, *internal integration*, *external integration*, and *value chain integration)* were translated from the purchasing function to the maintenance function while retaining the original characteristics levels in that process (maturity dimension and level definitions are provided in Appendices A and B). The maturity dimensions were operationalized for measurement purposes by linking these stages to the maturity dimensions. For each of the 23 dimensions, level descriptions were developed in terms of requirements that must be met to achieve each level. An interview guide and data recording sheets were developed to assess each dimension.

Determining the number of cases to include in a study relates to the desired generalizability of the findings. In this research, the purpose is not to develop a grand theory but to develop an adapted service triad for the meaningful involvement of purchasing in SMM. The findings from the individual cases are generalized into the adapted service triad, rather than to populations of cases. Due to practical limitations in terms of time and resources, this study was limited to four cases in the Netherlands. Nevertheless, by offering transparency about the context in which the maturity model and the adapted service triad were developed, and by providing information about the research procedures followed, readers can evaluate the research approach and interpret the relevance and validity of the findings (Dubois and Araujo, 2007). In the conclusions section, we discuss how our findings can be transferred to other empirical contexts.

Case study protocol and data collection

A case study protocol was developed by the lead author that included an interview guide and data recording sheets as research instruments. Four HEIs were identified by the lead author through contacting senior facilities managers and initial interviews were held to check the suitability as a case (Table I). The critical selection criterion was the outsourcing of maintenance. To identify respondents for each case, the lead author conducted an initial interview with the maintenance manager. For each case, again the lead author selected four respondents from the HEI itself and two from a contractor.

Table I. Case characteristics

The lead author evaluated the interview guide and data recording sheets in a pilot interview with a professional unassociated with the four cases. Subsequently, he developed a case study protocol and instructed multiple interviewers on how to use the interview guide and data recording sheets. The interviewers also received training from the lead author about the structure of the maturity model. Twenty-four on-line interviews were conducted by teams of two trained interviewers. During the interviews, the answers provided by respondents were systematically recorded on data recording sheets. To validate the maturity assessments, a three-staged approach was used. In the first stage, each team of trained interviewers established preliminary maturity levels for their case based on the data recording sheets. In the second stage, the lead author compared the preliminary maturity levels of all the cases to the data as a quality check. The purpose of this second step was to ensure a consistent assignment of maturity levels in accordance with the available evidence across all the cases. During this procedure, the evidence reported by the HEI and the contractors were combined (Figure 1). In several instances, this procedure led to corrected scores and additional clarifying questions for the second round of interviews. In the final stage of the validation, for each case, the lead author conducted an interview with the HEI's key informant to discuss any issues that were still unclear.

Figure 1. Procedure for assigning maturity levels

Data analysis

Two tactics were used in cross-case analyses to compare the maturity assessment data from the four cases: replication and differentiation. The data analysis was conducted by the lead author and was later checked by the second author. Both tactics were used to identify *value chain integration factors*: factors instrumental to the transition between maturity levels, which themselves had been conceptualized as stages in value chain integration. The replication tactic was used to look at cases with similar low-level assessments, because these might reveal barriers to maturity development. The differentiation tactic was used to analyze cases that were remarkably different from other cases. Distinct roles related to SMM were identified through hand-coding of the data recording sheets and the notes taken at the intake and exit interviews for the four case studies.

Results

Identified maturity levels

In general, the maturity levels determined in all the four cases were at the lower end of the maturity scale, with many scores of 2 or 3 out of a maximum of 6 (Table II). In terms of the maturity model, this reflects that, with respect to SMM, the HEIs' orientation is predominantly one based on commercial transactions and coordination. Higher levels of maturity were generally only found at HEI 2. To analyze the results in more detail and to identify value chain integration factors, as an intermediate step toward adapting the service triad, a cross-case analysis was conducted.

Table II. Maturity assessment data from four cases

Value chain integration factors

Value chain integration factors are defined as factors that are instrumental in the transition between maturity levels, which have themselves been conceptualized as stages in value chain integration. For the sake of parsimony, we only present the cross-case analysis results that produced value chain integration factors (Table III).

Table III. Identification of value chain integration factors

The low scores on 'Tracking and tracing of jobs' and 'Evidence-based contract administration' indicate that contract management and contract governance is predominantly based on data supplied by the contractor, creating substantial information asymmetries between the HEI and a contractor. The results suggest that HEIs are dependent on the tacit knowledge of contractors. Contractors, through their work at different sites and locations, accumulate location-specific knowledge and develop a social network with end-user departments. In one case, we found evidence that interactions between a contractor and an end-user department led to innovative solutions of which the HEI's maintenance management department was unaware.

Channeling communications is therefore considered a value chain integration factor because it enables the alignment of end-user initiatives with corporate policies, minimizes information asymmetries, and disseminates innovations across the HEI.

Applying the replication tactic to the cases with a low maturity score for 'Predictive maintenance' revealed *asset criticality assessment* as another value chain integration factor. In the maturity model, the low scores on this dimension can be traced back to the absence of a documented method for analyzing and recording asset criticality. Asset criticality rates the importance of assets for an organization's business operation and the lack of a criticality assessment presents a barrier to greater maturity. Although engineers will probably have some notion of criticality in technical systems, an impact assessment of the business and organizational consequences of equipment failures may require other expertise. As such, clarifying and defining 'asset criticality' in the higher education business context is seen as a value chain integration factor. While the low maturity scores for 'Lifecycle modeling' do not provide clear reasons for why none of the clients had adopted it, the absence of methods for analyzing and recording asset criticality could well be a reason for this.

Adopting a differentiation tactic when it comes to 'Energy performance measurement and verification' points to *smart maintenance sourcing planning* as a value chain integration factor. The high level of maturity of HEI 2 can be traced back to its advanced data integration of real time data streams with their second- and third -tier suppliers. This integration of real time data streams is absent in the other cases, suggesting that HEIs 1, 3 and 4 maybe do not know how to articulate their data needs or how to incorporate data supply as part of their purchasing arrangements. A sourcing plan for smart maintenance services could address this.

Distinct roles related to SMM

In the first round of coding, all references to purchasing related to smart maintenance were coded to gaint a general understanding of this practice within HEIs. From this first round of coding, it became clear that SMM in HEIs involves different contractual arrangements and a wide diversity of business operations: from office environments to gardens and lecture rooms, and from restaurants to laboratories, cleanrooms, and workshops. In the second round of coding, references to distinct areas of functional and technical expertise where coded. Here a distinction emerged between project-based and routine-based maintenance. All the references were grouped into three overarching categories (Table IV). Unlike the maintenance management and the ICT roles, the project management role is not characterized by physical assets but by characteristics of project-based delivery in the construction industry.

Table IV. SMM roles

Discussion

The findings from the case study are now used to reflect on how the digital transition in maintenance supply chains affects a client's purchasing department's involvement in SMM. First, we develop and discuss a service hexad for SMM based on our findings and, subsequently, we present three ways for purchasing to increase an HEIs SMM maturity.

From triadic to hexadic relationships

Triadic relationships have been applied to the pre- and post-tender stages to specify services and monitor service delivery quality and supplier performance (Van Weele, 2014; Van der Valk and Van Iwaarden, 2011; Wynstra *et al*., 2015; Holma *et al.,* 2020). These triads are used to organize human interactions among the supplier, the buyer, and end-users as service co-creators (Ellram *et al.,* 2004).

Our case study findings suggest that triads do not sufficiently describe the way that smart maintenance is specified, delivered, and monitored. The increasing digitalization of maintenance supply chains presents challenges that are not addressed by service triads. The reason why service triads may not accurately describe the interaction between buyer, supplier, and end-user, is that technical disciplines, despite their obvious role in SMM, are not incorporated in the service triad concept. The specification of services and the installation of sensors, measurement tools, and associated hardware and software, should be carefully tuned to the existing configurations of geometrical, mechanical, and electrical systems. As such, these project-based decisions cannot be taken in isolation from the client's technical disciplines and the existing maintenance contractor. Based on our study, a model based on six, rather than three actors more realistically describes collaboration in SMM. Based on the three SMM roles identified in the case data, we propose a hexadic configuration that mirrors the six key subject positions that have a permanent and long-term interest in smart maintenance specification, delivery, and monitoring (Figure 2). The buyer's role is broken down into four separate roles:

maintenance management, project management, ICT services, and purchasing, creating a service hexad. The service hexad more accurately describes the relationships between maintenance management, project management, ICT services, and purchasing and thereby reduces the risk of ambiguities between internal units. In the service hexad, purchasing serves as a bridge and a broker between project management, maintenance management, and ICT services, having oversight of all the suppliers and contractors that these functions use. Through the service hexad, purchasing can bring in valuable expertise and knowledge on risk management and legal affairs.

While some relationships within the service hexad are predominantly unidirectional by design, others are bidirectional (Figure 2). The bidirectional relationship between purchasing and end-user can be used to investigate user requirements and disseminate innovations across end-user departments. Two other bidirectional relationships (contractor – maintenance management and contractor – end-user) enable ongoing interaction over respectively the contractor briefing and the delivery of services. A key bi-directional relationship is the one between maintenance management and project management because both functions are known for their silo-mentalities (Kumaraswamy, 2011; Smyth *et al.,* 2019). The relationships of maintenance management with the end-user and with purchasing are predominantly unidirectional, aimed at collecting and absorbing data as maintenance management information. Well developed service hexads can contribute to client leadership in supply networks by creating communication channels for the diffusion of new technologies and by supporting the adoption of new ICT solutions (Peansupap and Walker, 2006).

Figure 2. A service hexad indicating necessary relationships for SMM

Toward purchasing involvement in SMM

Ueltschy Murfield *et al*. (2021) argue that, for meaningful involvement, purchasing needs to understand and communicate their value propositions in terms of innovation, margin enhancement, risk management, negotiations, and supplier management. Earlier in this paper, in the context of this study, we defined meaningful involvement of purchasing in SMM as the fulfilling of an intermediary role between the supplier and internal HEI units with the intention of increasing the HEI's SMM maturity. Based on the *value chain integration factors*, three ways for purchasing to increase SMM maturity can be identified.

First, when SMM is in its initial stages of professional development, building hexadic relationships should be purchasing's priority. This is because this will channel the interactions between actors. It will address the development of the fundamental inter- and intra-organizational trust on which higher levels of maturity are built (Schiele and McCue, 2006). Hexadic relationships can help develop SMM from a 'transactional orientation' (stage 1) toward a 'commercial orientation' (stage 2).

Second, when hexadic relationships are in place, the input and knowledge of end-user groups (budget holders such as faculties and business units) can be used to establish a shared and documented method and process for assessing asset criticality. Asset criticality integrates the risks of failures and the business value of assets. The main objective is to determine the consequences of potential failures and to prioritize maintenance policies and actions according to the associated risks (Márquez *et al.,* 2016; Gómez *et al*., 2019). 'Defining asset criticality' is related to several maturity dimensions (such as predictive maintenance) and key to progressing SMM from 'maintenance coordination' (stage 3) toward 'internal integration' (stage 4) as the next maturity level. The meaningful involvement of purchasing in asset criticality assessment could involve the integration of quantitative analyses and data science techniques within the overall corporate strategy and business objectives to achieve a collaborative shared understanding of those assets that are key to business performance (Tranfield *et al*., 2004). In doing so, purchasing will improve its value proposition through improved risk management (Ueltschy Murfield *et al*., 2021) and raise the maturity of SMM.

Third, once the 'internal integration' (stage 4) maturity level has been reached, purchasing could be involved in a smart maintenance sourcing plan to take SMM to the 'external integration' (stage 5) and 'value integration' (stage 6) maturity levels. These high levels of maturity are characterized by the use of advanced data analytics, real-time monitoring, and predictive maintenance approaches for critical assets. Traditionally, these data uses are impeded by poor data quality and data integration problems (Bosch *et al*., 2015; Becerik-Gerber *et al*., 2012). The meaningful involvement of purchasing could address these issues through a dedicated sourcing plan for smart maintenance. Such a plan would define the maintenance services and specify the data-sets for specific assets to be delivered by the suppliers in the supply network. In an ideal situation, the sourcing plan for smart maintenance services would offer solutions for managing distributed and dispersed datasets. Through the meaningful involvement of purchasing, decisions on data and information formats could be made in interaction with network partners and suppliers. The hexadic relationships could also be used to evaluate client needs and identify projects that fit within the smart maintenance sourcing plan.

Conclusions

This study provides insights into how purchasing can increase SMM maturity in construction clients by assessing current SMM maturity and by developing a service hexad for the meaningful involvement of purchasing in SMM. Data from maturity assessments of four HEIs were used to develop a service hexad that structures the collaboration between multiple client roles. Further, three ways were identified in which purchasing could increase SMM maturity: by building hexadic relationships, by defining and documenting asset criticality, and by developing a smart maintenance sourcing plan.

The implementation of the service hexad aims to provide construction clients with a stronger position in supply networks, redefining the purpose of both its maintenance management and project management roles. This will also alter the role of construction managers. While construction management's traditional role has focused on delivering the technical artifact, its future role will be influenced by an increase in data management tasks and responsibilities. The collection and supply of reliable, high quality asset data during construction and at handover will become an increasingly important part of construction managers responsibilities.

A stronger position of construction clients in supply networks brings potential improvements to professional practice on three areas. First, the extension of the construction management role with data supply responsibilities will improve all building related purchasing and procurement practices. The increased reliability of the asset register reduces information asymmetries between client and contractors and allows procurement costs to be estimated upfront with greater accuracy. Second, the incorporation of the project management, the maintenance management, and the ICT services functions in the service hexad enables a better articulation of the client's needs when defining multidisciplinary investment projects. This will improve the quality of the project definitions and the briefing practices. And finally, the service hexad enables systematic communication between project managers and maintenance managers within the construction client, fueling mutual trust between those groups with traditionally opposing interests, which in turn contributes to a more collaborative culture.

While the digital technologies of smart maintenance are promising, their implementation by construction clients is falling behind, due to the organizational changes that are required to benefit from the technologies. Many theoretical concepts, models and frameworks have been developed in the academic world that describe applications of digital technologies for smart maintenance. Construction clients and practitioners however, are struggling to apply that knowledge in real world settings. This study is an attempt to start bridging the gap between theoretical knowledge and the professional practice of construction clients, by designing a framework for collaboration (the service hexad) of six professional interest groups. Within the service hexad, new practices can be co-created. Replacing old practices by new ones, however, is complicated in large, institutionalized organizations. Further research therefore is needed into the behavioral change mechanisms that are associated with digitalization in construction clients.

While the findings of this study are derived from a particular class of construction clients (HEIs), they can, with some changes or further research be translated to other empirical contexts. Using ownership (owner-occupied versus investor-owned) and occupancy (single-user versus multi-user) as two axes of a two-by-two matrix, four empirical contexts can be distinguished that are relevant for transferring the proposed service hexad. The service hexad was developed based on owner-occupied properties, and this research did not compare the HEIs' single-user and multi-user properties. When applying the service hexad to owner-occupied multi-user properties, individual hexadic relationships will need to be developed with each individual user. This introduces additional questions with respect to user-representation, and the need to combine and integrate the needs, wishes, and desires of multiple users.

While implementation of the service hexad in owner-occupied multi-user properties might be a small step, transferring it to investor-owned rental properties is a greater step, and this will require further research. In investor-owned rental properties, tenants lease the property (or part of it) from the owner for short or long periods. This introduces additional contractual complexities related to the consequences of the various possible leasing arrangements. An important aspect is how the demarcation between owner's and tenant's rights and responsibilities for fixtures and finishings, and for mechanical and electrical infrastructure and utilities will influence the hexadic relationships for SMM. Another issue is the execution of ownership rights. On the basis that the owner exploits property for financial reasons, it is unlikely that the management of the physical assets is considered a core activity. When the various roles in the service hexad are outsourced by the owner to commercial agents, instead of being embedded in the construction client's organization, the service hexad will be governed by the various contractual arrangements that the owner has with tenants and service agents. How this will influence the enactment of roles within the service hexad, is a topic for further research.

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Appendix A

Appendix B

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Figure 1. Procedure for assigning maturity levels

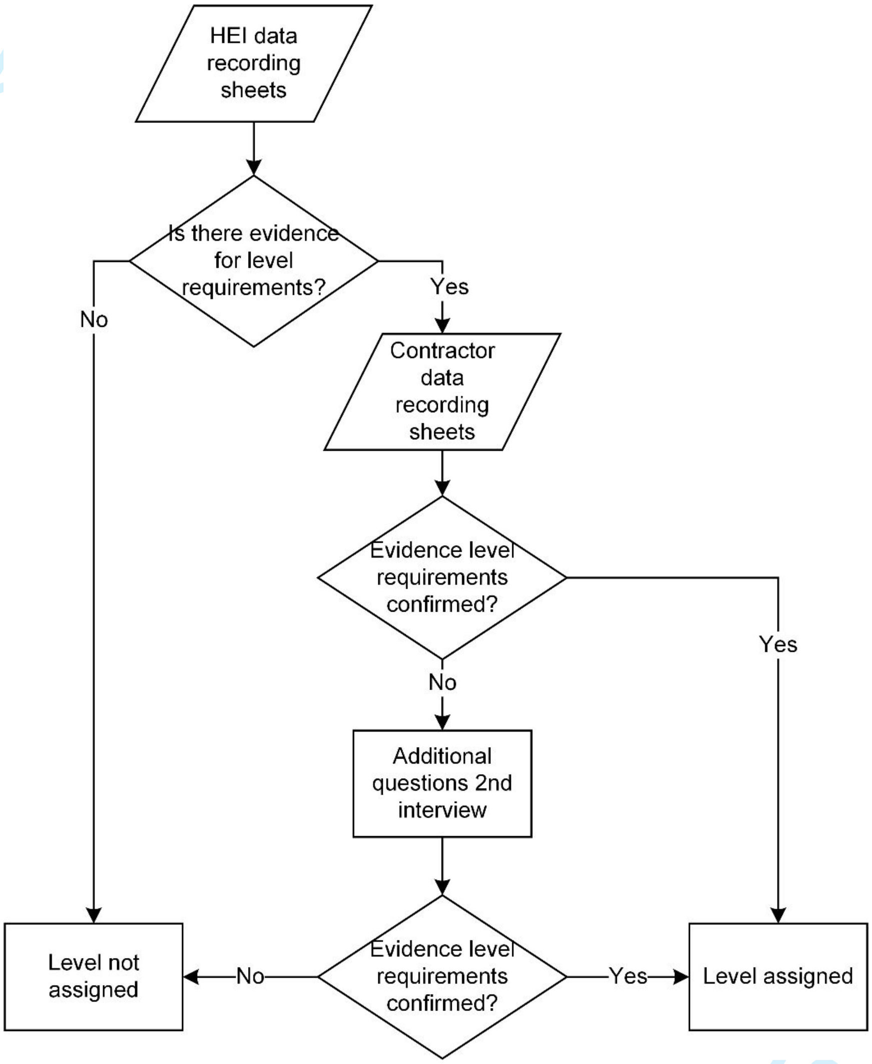

Figure 2. A service hexad indicating necessary relationships for SMM

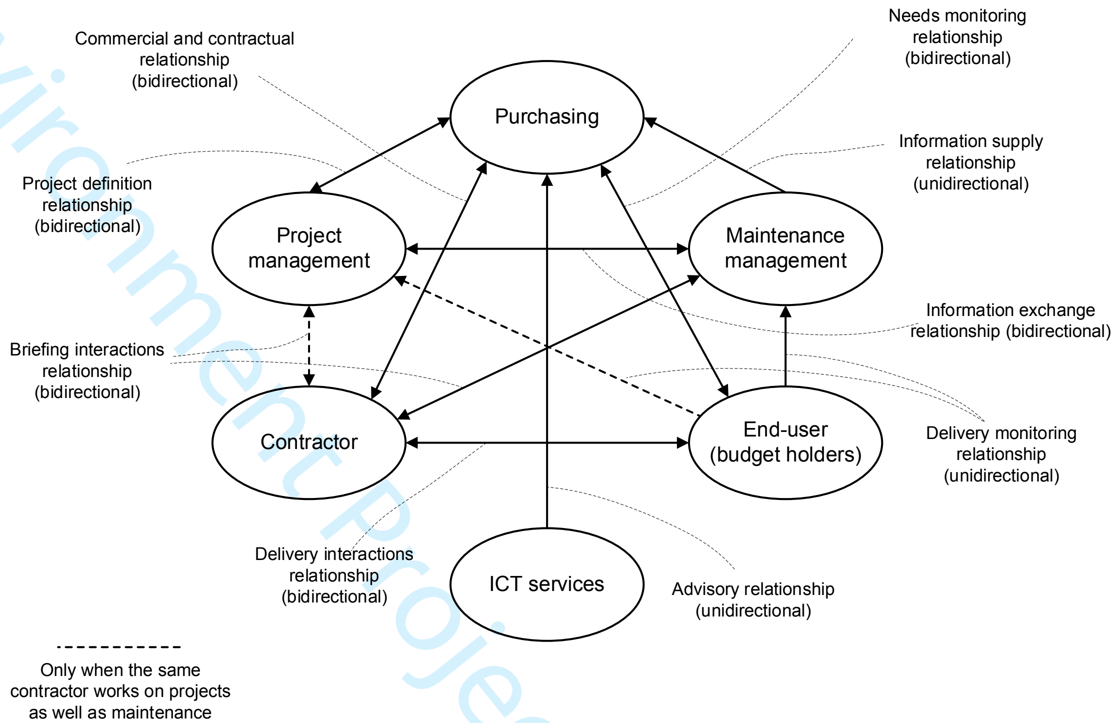

Table I. Case characteristics

	HEI 1	HEI 2	HEI 3	HEI 4
University	Applied	Research	Applied	Research
Students	25,700	24,100	27,300	26,600
Gross floor area (m^2)	125,570	387,000	127,000	440,000
Buildings	5	49	10	22
Spatial distribution	3 cities	1 city	3 cities	1 city

Table II. Maturity assessment data from the four cases

	HEI 1	HEI 2	HEI 3	HEI 4
Governance of projects	4	4	4	4
Governance of outsourced maintenance	4	4	4	4
Governance of asset data	3	5	3	3
Alignment of processes	3	3	1	3
Alignment of data definitions	3	3	1	2
Alignment of systems	3	4	1	2
Tracking and tracing of assets	3	4	2	2
Tracking and tracing of conditions	2	3	3	2
Tracking and tracing of jobs	1	1	1	1
Lifecycle modelling	1	2	1	1
Predictive maintenance	1	2	2	1
Evidence-based contract administration	1	3	1	1
Energy performance M&V	3	6	1	2
Asset monitoring and replacement programming	3	5	2	2
Project manager support	2	3	1	2
Maintenance contractor coaching	2	3	1	2
Knowledge creation	2	3	2	2
Maintenance needs and requirements	3	5	2	3
Handling non-standard asset data	2	3	1	1
Valuation of asset data	1	3	2	2
Innovation approach	2	4	3	2
Safe learning environment	2	4	5	2
Collaborative business values and goals	2	2	2	1

1 = transactional orientation; 2 = commercial orientation; 3 = coordination
4 = internal integration; 5 = external integration; 6 = value chain integration

Table III. Identification of value chain integration factors

Cross-case tactic	Cases	Maturity dimension	Value chain integration factor (VIF)	Barrier or driver?
Replication	1,2,3,4	Tracking and tracing of jobs	Channeling communications	Barrier
Replication	1,3,4	Evidence based contract administration	Channeling communications	Barrier
Replication	1,4+2,3	Predictive maintenance	Asset criticality assessment	Barrier
Differentiation	2 vs 3,4	Energy performance measurement and verification	Smart maintenance sourcing planning	Driver

Table IV. SMM roles

SMM role	Functional and technological domains
Project management	New construction, new installations, European procurement rules, construction supply chain management, project handover
Maintenance management	Existing buildings, building services, lighting, HVAC*, power plants, energy systems and utilities, water supply and sanitation, sensing and measurement systems, vertical transportation, security, fire safety, BMS, building regulations, health and safety inspections
Information and communication technology (ICT)	Hardware, software (as a service), information architecture, (wireless) networks, cloud-based data storage, data security

*: HVAC: heating, ventilation, and air conditioning
**: BMS: Building management system

Appendix A

Governance structure		
1.1	Governance of projects	Describes how responsibilities for initiating and delivering projects are allocated. Includes projects related to new construction as well as refurbishments and replacements.
1.2	Governance of outsourced maintenance	Describes how responsibilities for maintenance and maintenance outsourcing are allocated. Includes corrective as well as planned preventative maintenance.
1.3	Governance of asset data	Describes how responsibilities for defining, capturing and storing of asset data are allocated.
Alignment		
2.1	Alignment of processes	Refers to the way in which the processes and work instructions of the maintenance department are documented and aligned with internal teams, external contractors, and service agents.
2.2	Alignment of data definitions	Refers to the way in which asset data definitions of the maintenance department are aligned with those of the capital works team, external contractors, and service agents.
2.3	Alignment of systems	Refers to the way information systems, tools, and applications of the maintenance department are aligned with those of the capital works team, external contractors, and service agents.
Tracking and tracing		
3.1	Tracking and tracing of assets	Refers to the way the maintenance team identifies individual assets and according to which level of detail an asset register is operated.
3.2	Tracking and tracing of condition	Refers to the scale and frequency of condition audits by the maintenance organization.
3.3	Tracking and tracing of jobs	Refers to the way individual maintenance jobs and their costs can be traced back to individual assets.
Data-driven decision-making		
4.1	Lifecycle modelling	A structured and systematic approach to analyze and predict the service life of assets and asset classes.
4.2	Predictive maintenance	The ability to implement and use predictive maintenance policies for critical assets.
4.3	Evidence-based contract administration	Supporting the purchasing department with evidence-based information about the number of maintainable assets and maintenance jobs.
Sustainability monitoring		
5.1	Energy performance measurement and verification (M&V)	The consistent evaluation of the energy performance of assets and asset infrastructure configurations. Energy performance assesses the efficiency of asset infrastructure in delivering output at given business operation levels (heating, cooling, ventilation, etc.) related to inputs used (gas, electricity).
5.2	Asset monitoring and replacement programming	Systematic and regular review and analysis of the asset portfolio from a lifecycle perspective with the purpose of improving overall sustainability performance by upgrading assets.
Knowledge management		
6.1	Project manager support	The methods used to train, instruct, and coach project managers in their data capturing roles during project delivery and handover.
6.2	Maintenance contractor instruction and coaching	The methods used to train, instruct, and coach the maintenance contractors and inspection agencies in barcoding assets, tagging maintenance jobs to assets, and tagging condition audits to assets.
6.3	Knowledge creation	The methods and procedures used to combine explicit and tacit information.
6.4	Maintenance needs and requirements	The processes and methods used to articulate, express, and specify projected maintenance requirements in terms of both volume and technical and functional specifications.

Culture		
7.1	Handling non-standard asset data	The behaviors of individuals in dealing with unfamiliar, unknown, and non-standard facts, information, and data.
7.2	Valuation of asset data	The behaviors of individuals in recognizing the value of asset data for improving maintenance processes.
7.3	Innovation approach	The policies and practices adopted for improving existing data-driven services and developing new data-driven services.
Leadership		
8.1	Safe learning environment	The practices and methods used to create a safe environment for trying and piloting new ways of working.
8.2	Collaborative business values and goals	The practices and methods used to establish common business values and goals in the relationships with internal and external stakeholders.

Appendix B

Stage 1	Transactional orientation	In this stage, the maintenance organization is orientated towards operational and administrative activities. The primary focus of the maintenance organization is to ensure the daily operations of a building's facilities and systems. Maintenance jobs are outsourced in a rather improvised manner and in various, somewhat random, work packages. There is no systematic way of creating maintenance work packages. For the same service category, there are many different contractors at work.
Stage 2	Commercial orientation	At this stage, a more proactive approach to maintenance and maintenance outsourcing is to be found with a focus on cost control. Maintenance is considered a cost to the organization and maintenance strategies are aimed at controlling costs, measuring contractor performance, and realizing savings. Maintenance purchasing is aimed at comparing prices, obtaining competitive bids, and negotiating with suppliers.
Stage 3	Maintenance coordination	In this stage, maintenance and asset data are not viewed as a cost to the organization but as a service with a quality of its own. The maintenance organization develops activities aimed at improving communication with end-users and business units as well as with other CFM functions. It collaborates with internal business units and has oversight over the maintenance portfolios.
Stage 4	Internal integration	In this stage, the maintenance organization enjoys a good collaboration with end-users, business units, and other Corporate Facilities Management functions such as capital works, procurement, and real estate management. The data and information systems of the maintenance organization are aligned and integrated with those of other functions. Cross-functional teams are used to solve intra-organizational maintenance problems. Key maintenance contractors and data- or ICT-suppliers are often involved in cross functional problem solving.
Stage 5	External integration	In this stage, the originally large number of contractors has been decreased to a small group of preferred or key maintenance contractors or data- and ICT-related service agents. These are actively involved in process innovations and new service developments aimed at creating end-user value. Information systems are not only internally integrated but also externally with those of suppliers.
Stage 6	Value chain integration	In this stage, maintenance subcontractors and specialized suppliers and their partners are constantly challenged and invited to contribute to the continuous improvement cycle of the maintenance organization. In an entrepreneurial culture, the goal is to develop the most effective maintenance value chain for servicing end-users and the business units.