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Construction-Related Data Management: Classification and Description of Data from Different Perspectives

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The productivity improvement of the construction sector has fallen behind other industries. One potential factor is the on-site nature of the work that may not allow for as industrial way of operations as off-site construction. Also, the division into non-optimised chain of domains of architecture, engineering, construction and facilities management may play a role. The construction objects may not be considered as products that would necessitate careful consideration of the product structure, both commercially and technically to optimise the use of platforms, assemblies, components, and materials while offering what customers desire. Furthermore, the life-cycle of building objects and the varying needs during design, construction and the use-phase are not acknowledged effectively. Addressing the life-cycle of building objects necessitates taking command of the relevant data and understanding the bigger picture. Currently the data are managed in an un-organised manner. This study aims to form the pre-requisites for managing construction object-related data. The study is realised as a combination of a literature review and analysing constructors' offerings, requirements plans, Ministry reports, and building control documentations. A rather detailed example of construction object related data management is presented to discuss master data, and business process related data in the context of business processes and enterprise applications, and different Bills-of-Materials (BOM) configurations to demonstrate the necessary considerations. The example also acknowledges the product structure, necessary parameters, and stakeholders. New contribution is provided by presenting valuable insights with a broader scope for setting up effective data management in the construction sector.

Keywords: data management, master data, business data, construction industry, BOM configurations, product structure, business processes, enterprise applications, productization, product management

Introduction

The productivity of the construction industry is widely recognised as poor with negligent improvement (Fulford & Standing, 2014). The industry has,

however, shown minor steady development like many other industries, but there is no match to the development rate of the best industries (Pekuri, Haapasalo, & Herrala, 2011). The on-site nature of the construction industry is one potential source of inefficiency as the construction activities take place at the site of construction (Eastman & Sacks, 2008). On-site activities are likely not possible to optimise industrially the same way as off-site construction and prefabrication. As a result, the cost of construction increases, and the prices of construction objects remain high. Industrialisation of construction and the increase of off-site activities might allow construction industry to act more like production industry and incorporate the latest product and process technologies and utilise automation to increase productivity (Linner & Bock, 2012).

The product structure concept is not widely utilised in the construction industry to provide a manageable logic for the construction offering (Harkonen, Tolonen, & Haapsalo, 2018). One example of this is apparent in industrialised construction where construction objects are produced in a factory to be installed at the construction site. The factory production takes place based on drawings or an illustration without exact details on materials to be used. This allows to produce as the employees see the best and may cause variation in quality based on differences in employee competence profiles. The concept of the Bills-of-Materials (BOM) is widely used in industrial sectors other than construction, and the product structure is central to enterprise applications such as ERP and PDM/PLM (Boton, Rivest, Forgues, & Jupp, 2016). Both concepts, product structure and BOM can be beneficial for the construction industry to convey information. Product structure is needed to provide an organised hierarchy of technical objects that are linked via 'part-of' relationships (Pinquié, Rivest, Segonds, & Véron, 2015), and BOM to list the raw materials, sub-assemblies, intermediate assemblies, sub-components, parts, and the quantities of each needed to produce the object. Hence, product structure can have a role in organising the data that relate to construction objects (Boton et al. 2016)

The data management in the construction industry is challenged by the fragmentation into domains of architecture, engineering, construction and facilities management (Jiao et al. 2013). Data generated by one domain should be possible to share and be usable by others (Cerovsek, 2011). The project nature of construction industry also affects the data management (Bakis, Aouad, & Kagioglou, 2007). A construction project may consist of multiple phases such as tender, design, construction, and maintenance, and involve a variety of parties such as owners, architects, consultants, engineers, contractors, sub-contractors, and suppliers who all create data, whereas a project may utilise various IT systems (Shen et al., 2010). How well the diverse IT systems can manage and communicate electronic prod-

uct and project data in such a fragmented environment can be a challenge (Jiao et al., 2013).

The practical challenges involve the life-cycle of building objects, and the variety in needs during the life-cycle that are not typically acknowledged. The needs during the design, construction, and the use-phase all have their specific focus. Building information modelling (BIM) has the potential to provide tools for managing construction object-related data through the life-cycle (Jiao et al., 2013) by covering construction process-related information in a digital format (Cerovsek, 2011).

The structuring that BIM is lacking would, however, be needed to improve the feasibility, design, construction and operational processes (Holzer, 2014). Thinking of productivity, the individual perspectives may not contribute towards the overall productivity. The architect may not aim to optimise the used components or number of different components to benefit construction, ignoring that some components are more cost-effective to use during construction and sourcing a smaller variety improves productivity. Similarly, the customers' perspective is important in terms of requirements, what the customer really wants and what are the boundary conditions for realisation. Also, the owner's or the maintenance company's perspective involving questions over the components the building object constitutes is important. The data and documentation are either missing or exist in a non-user-friendly format, which prevents knowing which components or materials have been used, and who has provided the materials. Also, should something break during the use-phase, a typical situation involves a maintenance person analysing locally which tap, or which building material needs replacing, instead of just checking the use-phase related data. The more complex the product, the more important it becomes to manage the various structures that allow the handling of the data generated along the life-cycle (Hameri & Nitter, 2002).

The construction industry is behind other industrial sectors in data management. The data are not managed in an organised manner. Fragmented documentations do exist, and they are managed to a varying degree. The data are not used as an asset to improve productivity and a data model is missing completely. This applies to large actors in the construction sector, not only the smaller ones. The initial awakening has taken place in the form of BIM efforts, but the ability to manage the whole is missing. The lack of adequate data management is weakening the true industrialisation of the construction sector.

This study aims to form prerequisites for data management and creating a data model for the construction industry by analysing construction object-related data. The above discussion can be condensed into the following research question:

How should construction object-related data be classified and described?

It is attempted to answer the research question by the means of an extensive literature review and by providing an example of construction object-related data management to discuss master data, and business process-related data in the context of business processes and enterprise applications, and different BOM configurations.

Literature Review

Product Data Management

Product structure has an essential role in organising data (Boton et al., 2016). Product structure is a hierarchy of a product into a structure to describe the decomposition of a product of any nature, physical, service, software, or their combination (Tolonen, Harkonen, & Haapsalo, 2014; Harkonen et al., 2017, 2018). The decomposition may vary depending on the use of the structure (Svensson & Malmqvist, 2002). The structure also has a role in managing bills-of-materials and various product configurations, providing functionalities for versioning, and linking parts (Eynard, Gallet, Nowak, & & Roucoules, 2004). A product data management (PDM) system is an enterprise application that can be used to manage the product structure (CIMdata, 2001), typically the technical side. The significance of the commercial structure is not widely understood in companies. Standards such as STEP (Standard for the Exchange of Product Data Model) also take a position on product data, enterprise applications and the product structure (Pratt, 2001). Different disciplines, such as design, manufacturing, purchasing, order management, spare parts, and service have varying needs for the decomposition of product structure and the functionality of the enterprise applications, hence they tend to work in different systems (Svensson & Malmqvist, 2002). Bill-of-Material (BOM) is the most common product structure that identifies echelon relations and reflects product assembly, often used in manufacturing related activities (Wu, Chien, Huang, & Huang, 2010), the technical composition. BOM structure is the structure often used in PDM systems with added metadata. The master structure can reside in PDM/PLM (Product Life-Cycle Management), or in ERP (Enterprise Resource Planning) and is transferred to other enterprise applications (Hannila, Tolonen, Harkonen, & Haapasalo, in press; Svensson & Malmqvist, 2002). The set of enterprise applications, their integrations and data transfer mechanisms may vary among companies.

The commercial composition is often not systematically linked to the enterprise applications in companies, even though the commercial side links to the customer focus, sales, marketing, and product management (Tolo-

nen et al., 2014). The commercial structure also supports sales offers, contracts, orders, deliveries and invoicing (Tolonen, Harkonen, Haapsalo, & Hannila, 2018). The commercial product or service structure hierarchy can consist, for example, of product families, product configurations and sales items (Harkonen et al., 2017, 2018; Tolonen et al. 2014, 2018). The commercial structure is also possible to form amongst several companies to cooperate commercially (Mustonen, Tolonen, Harkonen, & Haapasalo, 2019). There are no differences in the logic of a commercial portfolio of products or services (Harkonen et al., 2018; Tolonen et al., 2018). The difference lies on the technical description. The product structure may also benefit company analytics by forming a frame for fact-based analysis (Lahtinen, Mustonen, & Harkonen, in press). The main aim of product structure and the related master data is to reach data consistency to enable fact-based analysis (Hannila, Koskinen, Harkonen, & Haapasalo, in press). For example, product profitability is possible to analyse in real time by comparing sales and cost information with the support of enterprise applications, data and product structure (Hannila, Tolonen, et al., in press). This, however necessitates the use of both commercial and technical structures.

The technical product structure is not static and necessitates data and product structure updates in the enterprise applications (CIMData, 1998; Hannila, Tolonen, et al., in press; Pinquié et al., 2015). Engineering Change Management (ECM) takes place through the life-cycle of a product and affects the product structure (Svensson & Malmqvist, 2002). Quality improvement or cost reduction activities may also affect the technical product structure. Verrollot, Kaikkonen, et al. (2017) illustrate the focus on product structure in case of activities of different nature, indicating that the focus should be sometimes limited to avoid extensive ripple effects.

The product structure concept relates to the concept of productization that deals with managing of products and services and the commercial and technical product portfolios (Harkonen et al., 2018; Mustonen, Seppänen, Tolonen, Harkonen, & Haapasalo, in press; Tolonen et al., 2018). Productization is a process of analysing a need, defining and combining suitable elements, into a product-like defined set of deliverables (Harkonen, Haapasalo, & Hanninen, 2015). Productization is also beneficial for managing a service offering (Harkonen et al., 2017). Due to the nature of services, productization allows actions by customers to be described along the same structure (Kuula, Haapasalo, & Tolonen, 2018). Hemple (2018) considered the market context in conjunction with service productization. The concept has also been demonstrated in the construction context (Harkonen et al., 2018). Unnecessary new technical descriptions of the same product can be avoided by forming the offering based on defined sales items to the extent that is possible. Logic must exist for introducing new sales items. The in-

efficiency that involves products and services can be addressed (Jaakkola, 2011; Valminen & Toivonen, 2012). The concepts of productization and product structure link to product portfolio management, and the life-cycle of products (Hannila, Tolonen, et al., in press; Tolonen et al. 2014; Tolonen, Shahmarichatghieh, Harkonen, & Haapasalo, 2015a; Tolonen, Harkonen, Verkasalo, & Haapasalo, 2015; Verrollot, Tolonen, Harkonen, & Haapasalo, 2017).

The product structure, productization, and enterprise applications are linked to company business processes. The role of traditional business processes should be to define how products are developed, sold, marketed, supplied, manufactured, ordered, delivered, invoiced, installed, maintained and repaired (Tolonen et al., 2014; Tolonen, Harkonen, et al., 2015; Hannila, Tolonen, et al., in press; Harkonen et al., 2017; Kuula et al., 2018). The product data, the information about the product, are linked to the integration of the functions and business processes of a company. The creation, development, handling, division and distribution of data connect the expertise of the organisation (Sääksvuori & Immonen, 2008).

Due to the volumes of data, companies utilise specific applications to manage product master data (Silvola, Jaaskelainen, Kropsu-Vehkapera, & Haapasalo 2011), which are then utilised over the life-cycle of the product (Stark, 2011; Silvola, Tolonen, Harkonen, Haapasalo, & Männistö, 2019; Hannila, Tolonen, et al., in press). In fact, Aiken and Billings (2013) view the value of data as that of a strategic company asset. Master data are defined as cleansed, standardised, and enterprise-widely integrated critical business information that relate to companies' transactions and analytical operations (Das & Mishra, 2011). Master data connect enterprise applications and business processes (Das & Mishra, 2011). Silvola et al. (2011) have linked the data, processes and IT applications and emphasised the importance of master data quality to the level of human DNA. Product master data are created during the design process, and then released for use by other company functions and business processes (Silvola et al., 2019). Product-related business data, on the other hand, relate to the business processes and includes product-related marketing and sales data, supply chain data, and service and care data. These data are utilised in the business processes and support the business transactions (Silvola, 2018).

Figure 1 synthesises the literature review and links construction object related master data, business data, business processes, product structure, and enterprise applications. Productization and product structure are prerequisites for effective construction object-related data management and provide a necessary structure to reach data consistency. Product structure is ideally stored in the same enterprise application as master data, at least for the technical part. The commercial part can be stored separately but

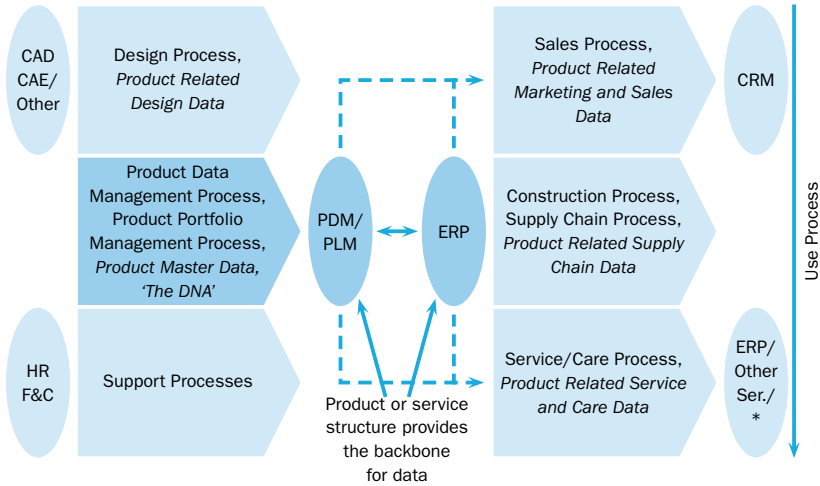


Figure 1 Literature Synthesis, Construction Object Related Master Data, Business Data, Business Processes, Product Structure, and Enterprise Applications (light – business data (reside in enterprise applications), dark – master data (reside in PDM/PLM system; ERP or BIM 2.0 if no PDM/PLM?), dashed arrows – master data are copied from the application they reside to other enterprise applications, * maintenance/care application)

must be linked to the technical structure. Enterprise applications relate to the business processes. The set of applications may differ from the presented but should have similar role and functions. If a company has a PDM/PLM system, then this is a natural location for master data. Master data are then copied to other enterprise applications. ERP may adopt the role if necessary, or the next generation of BIM, BIM 2.0 should there be prerequisites in terms of structure and function. Master data are the 'glue' that holds things together. Construction-related standards are acknowledged as a default.

Research Process

The study is realised as a combination of a literature review on relevant topics, analysing requirements for construction plans and reports based on decrees set by the Finnish Ministry of the Environment and the documentations by the building control of the biggest cities in Finland Helsinki, Vantaa, Espoo, Turku, Tampere, and Oulu). The requirements for construction plans and reports were analysed to ensure that all the mandatory design requirements are acknowledged. Otherwise, the discussed concepts are generic and applicable also elsewhere. In addition, the offering by various constructors are analysed. The purpose of analysing the offering by constructors was to analyse real construction objects in terms of how they

are structured, and to demonstrate the discussed concept. A hypothetical example of construction object-related data management is created to discuss master data, and business process related data in the context of business processes and enterprise applications. Different BOM configurations are discussed in conjunction with the example. Product-related ownerships, stakeholders and relevant requirements and parameters are linked to the discussion to provide real context for the example. The construction object-related data management is linked to productization and product structure. The construction object-related data management is modelled by using real boundary conditions to enable true applicability.

The literature review aims to provide relevant understanding over the importance of construction object-related data management as an enabler for industrialisation of construction industry and utilisation of enterprise applications. The basic requirements for construction object-related data management are attempted to synthesise through discussing productization and products structure in the business process context and providing an example of linking the enterprise applications to the context. The role of master data and the business process-related data are attempted to clarify for the construction industry context. The industry-related standards and legal framework are analysed to a necessary degree. The literature review is realised by conducting key-word searches and analysing content that is seen as relevant.

The presented example is considered to the extent possible by publicly available material. The real offering by various constructors are utilised. The information on constructors' offering have been obtained from publicly available materials. The construction companies whose offering have been analysed include Honka, Kontio, and Mammuttihirsi. The companies were selected by the means of convenience sampling in search to find easily understandable construction offerings as a way to create a realistic example to demonstrate the discussed concept. In convenience sampling, the researchers choose a sample from a population (Etikan, Musa, & Alkassim, 2016). Cases are selected based on their availability for the study (Henry, 1990). This type of sampling has limitations, which include non-random selection of research objects, potentially making researchers subjective and biased (Etikan et al., 2016). Generalisation of results may not be fully allowed due to the likely bias (Henry, 1990). Adequate availability of materials was also a criterion, further promoting convenience sampling. The construction object-related data management is considered in the context of construction setting. The presented data management concept has not been reviewed with construction professionals. The data management of different construction actors is possible to analyse against the example presented in this study.

Results

Construction companies do not seem to manage their data adequately even though many actors have taken some efforts towards digitalisation. There has been awareness over the lack of productivity improvement in this industry sector for decades, but no one has had the magic wand to rectify the situation. Digitalisation and industrialisation of construction are possibilities that may support improving the productivity. Managing construction object related data so that they have true significance for the operations, and to create meaningful information and value, are necessary to be considered alongside integrating the business processes and data processes. Offering a centric approach is needed with the support of productization and product structure to provide the basis for effective data management and analysis. The productized construction offering needs to be linked with the relevant business processes and enterprise applications. This whole needs to be considered alongside construction object-related master data and business data. All these together may provide essential prerequisites towards creating a data model for the construction industry, and the true digitalisation of the industry in a meaningful manner.

As a major result of this study, an example of construction object-related data management is created to discuss basic principles of master data, and business process-related data in the context of productization, product structure, business processes and enterprise applications. The life-cycle and the varying needs in different stages are attempted to acknowledge by discussing different BOM configurations alongside the example. The necessary construction offering-related ownerships, stakeholders and relevant requirements and parameters are linked to the discussion to enable true applicability.

Figure 2 illustrates examples of construction object-related master data and business data. Construction object-related master data includes the data that are created during the design phase. These data are then released to be used by other company functions and business processes. These data are validated at different phases of the design process and related meetings to ensure they meet the needs of the business processes. The nature of master data necessitates uncompromised data quality. Master data must be understandable by the layman. One possibility to store and manage master data is to utilise a PDM/PLM system, but other solutions may also exist. The focus ought to be on avoiding a situation where master data are not systematically tracked and controlled. Construction offering-related documentation, versions, processes and work-flows, product structure and components must be managed effectively to cope with the complexity. Nevertheless, the project nature of construction business

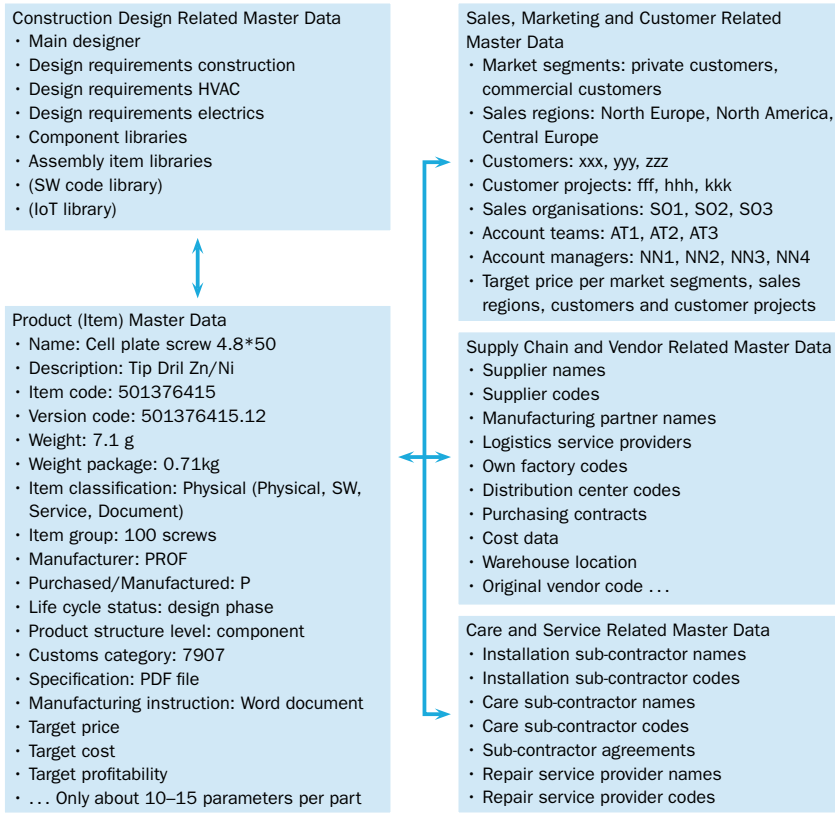


Figure 2 Examples of Construction Object-Related Master Data and Business Data

might also be necessary to acknowledge, should a PDM/PLM system be utilised.

Construction design-related master data must include information on the designers and different designs. Designs requirements at least for construction, heating, ventilation, and air conditioning (HVAC), and electrics are necessary. Construction design master data must also contain component libraries, and assembly item libraries. Should the construction design involve software (SW), or Internet of Things solutions in the form of sensors and Internet connectivity, then the corresponding libraries should be part of the construction design master data.

As local law and building control may set requirements for construction, the necessary compatibility may need to be considered alongside the data. Variety of plans may be required, such as the construction design and site plan. There may also be a variety of additional plans, such as floor plan, cutting drawings, and facade drawings. In addition, special plans such as

structural drawings and structural calculations, including loads, strength of bearing structures, measurements, and the insulation of thermal moisture, water pressure, noise and vibration insulation may be required. Hence, the construction object-related data must be considered accordingly.

Product (Item) master data should contain 10–15 parameters for each part necessary for the construction object. The presented example involves a screw that is needed to attach a cell plate that forms light roofing. The necessity to manage master data may help in guiding construction design towards utilising as many common components as possible in construction design, and further improve productivity. Or otherwise said, design construction objects by only utilising a certain set of components.

The business process related master data are also necessary to be defined, including sales, marketing- and customer-related operations, supply chain, and vendor, and care- and services-related master data. The necessary related parameters must be carefully considered. The related considerations also include the enterprise applications that the construction company must set a meaningful master/slave logic for the applications, that is where the master data reside. The data are then copied to the other applications. In general, master data are usually non-transactional information about customers, products, employees, materials, suppliers, and vendors.

Construction object-related business data mean in practice product data with business process-related additional data that are needed to perform the process-specific transactions. The business data can be stored in the specific applications that link to the corresponding business processes. The nature of business data is different than that of master data, as business data can change and are not as critical in terms of minor issues in related data quality.

Finding 1 *Master data and business data are necessary to be defined and considered to support construction object-related data management. This may also support considering the roles of business processes, enterprise applications and the data.*

Figure 3 illustrates construction-related business processes and data in the context of BOM configurations at different life-cycle stages. Bills of materials (BOM) relate to the technical productization of the construction object, the technical side of the product structure. Different BOM configurations are needed to consider and effectively manage the life-cycle of a construction object. The needs at different life-cycle stages vary, hence the differences must be acknowledged by the means of product structure and data. The technical product structure can be managed in a PDM/PLM system or in ERP. Where the commercial product structure should be managed is yet another question. Regardless of where the technical side is man-

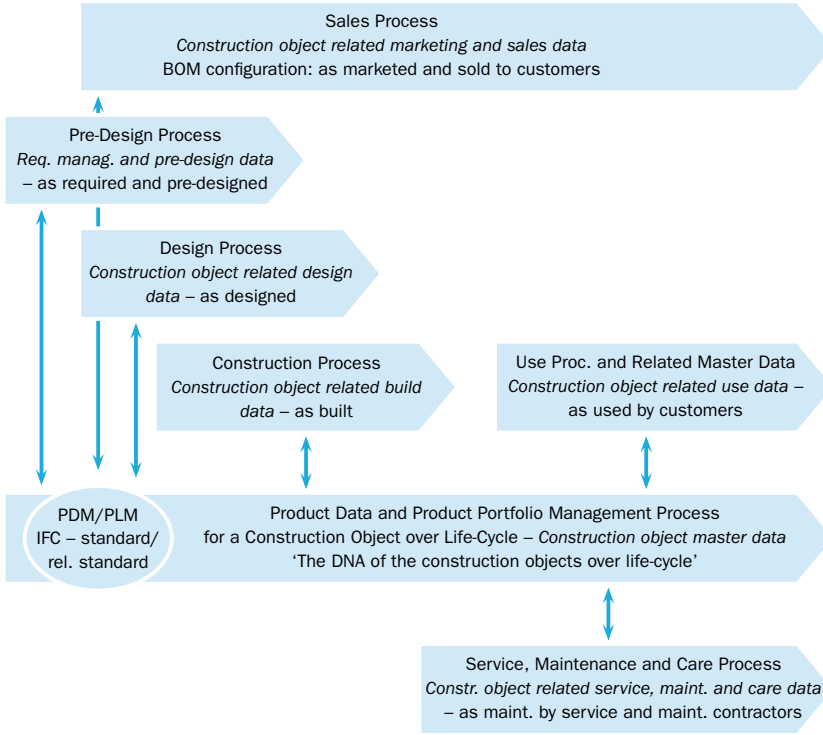


Figure 3 Construction-Related Business Processes and Data in the Context of BOM Configurations

aged, the configurations must be reconcilable to support effective BOM management. This supports identifying impacts of changes from different perspectives, technical, documentary, or other, and further track histories and causes. BOM configurations also enable comparing construction objects in different life-cycle phases. *As designed* configuration, for example, may support developing material plans in ERP. In general, information can be obtained along the same structure. The BOM configurations further support effective configuration management.

A business process for analysing and deciding on company's products now and in the future, the construction product portfolio management should deal with the DNA of the construction objects over the life-cycle. The enterprise application that stores the construction object master data links logically to this business process. The relevant construction industry standards should be considered alongside the data management. The role of the other business processes would then be to define how construction objects are designed, sold, constructed, supplied, manufactured, ordered, delivered, invoiced, installed, maintained, and repaired.

The most obvious BOM configurations relate to the sales process, that is, how the objects are sold and marketed to customers. The data that link to the sales process involve the marketing and sales data. To take the specific nature of the construction industry into account, a pre-design process can be necessary to link to *as required and pre-designed* BOM configuration. The data involve the requirements and pre-design data. Design process relates to the actual design of the construction object, *as designed* BOM configuration, and the design data. The design process and the pre-design process can be partially simultaneous. The construction process relates to the actual construction, *as built* BOM configurations and the build data. As construction objects are used, the use process should be considered. The use process relates to the BOM configuration *as used* by customers, and the use data. Service and maintenance processes relate to the *as maintained* BOM configuration and the related service, maintenance and care data. As the nature of certain processes is such that the same actor does not always take care of these processes, the needed applications should be considered carefully. For example, should there be a separate maintenance company, the original constructor should provide the necessary BOM configuration.

Considering construction object-related business processes and data in this type of context allow linking to relevant stakeholders and relevant standards. It should be understood how a construction object can be a house, building, bridge, road, city, or other construction related object.

Finding 2 *Considering construction-related business processes, data, and BOM configurations may prove beneficial for promoting meaningful data management and digitalisation.*

Figure 4 illustrates how a construction object can be linked to commercial productization and the product structure. An example of a log house is utilised to demonstrate master data in conjunction with construction product configuration and a sales item. It should be understood how a product configuration is constituted of sales items, both of which can be given a price as the company knows the corresponding technical composition and the related costs. It is the commercial product portfolio that is typically visible to the customer. The company can use different logics for productizing the offering along a logical product structure. The master data can be stored in a PDM/PLM system, as well as the technical side of the product structure can be managed through a PDM/PLM system, or ERP. The main open question remains where companies should manage the commercial product structure as reluctance may exist in involving the commercial side in an individual application.

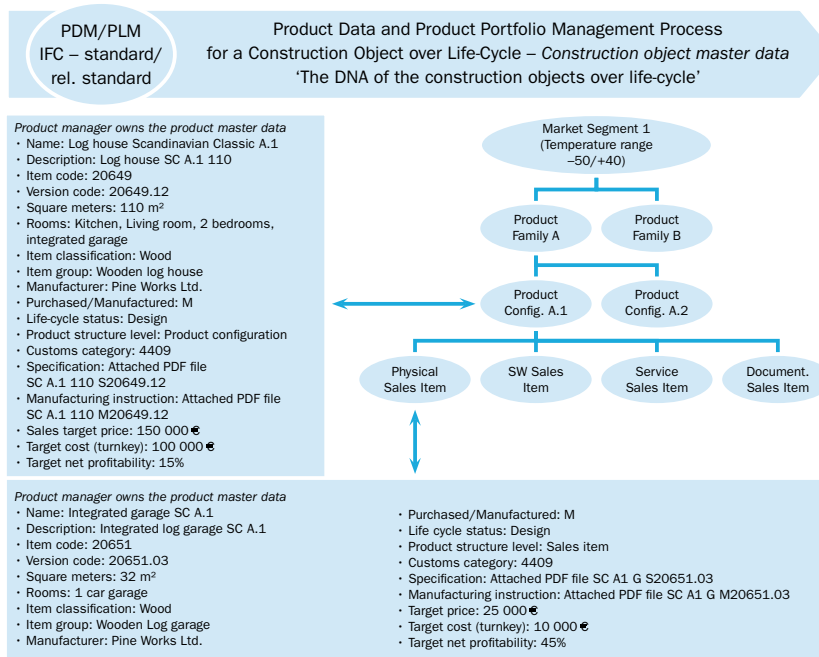
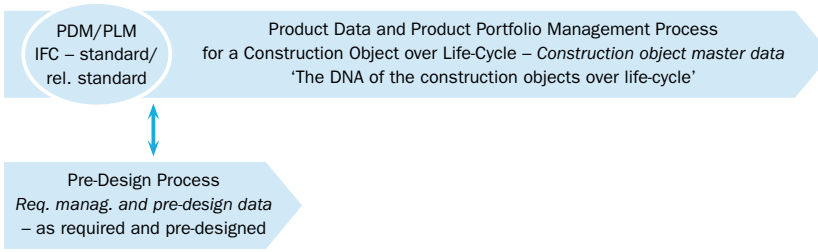


Figure 4 Construction Object Related Master Data and Commercial Productization

Finding 3 *Construction object-related master data can be linked to commercial productization in a meaningful way.*

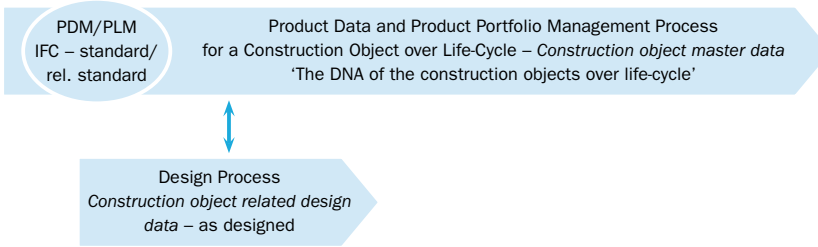
Figure 5 illustrates the linkage of a pre-design process, requirements management, and pre-design data, and the *as required and pre-designed* BOM configuration. The data created during the design process are fed to the application that is selected to manage the data. The application can be a PDM/PLM system, one that can acknowledge the industry specifics. Noteworthy is that PDM/PLM systems are not yet very common within the construction industry, not even with large actors, as data are currently insufficiently considered. If design systems are utilised, they should be linked to the pre-design process. The log house specific example illustrates important requirements, potential related stakeholders and which requirements are stored in the system that is used to manage data.

Similarly, Figure 6 illustrates the construction object-related design data and the *as designed* BOM configuration in the design process context by using the same log house example. The design process can and should utilise the previous data with the support of product structure and feed the used data management system as the source of master data. If design systems are utilised, they should be linked to the design process. The de-



Requirements	Stakeholder	Product master data in PDM
Temperature range: –50°C/+40°C	End-customer, Sales manager	x
Square meters: 110 m²	End-customer, Sales manager	x
Rooms: Kitchen, Living room, 2 bedrooms, integrated garage	End-customer, Sales manager	x
Material type: Log Wood	End-customer, Sales Manager	x
Life-cycle status: requirements management and pre-design	Product manager	x
Product structure level: product configuration	Product manager	x
Original customer requirement specification: attached PDF file SC A.1 110 C20649.12	Sales manager	
Country, area and community related specifications: Finland, rural area, Inari	End-customer, Sales manager	
Type of construction site: Lake side, Sandy soil	End-customer, Sales manager	
Legal requirements:…	Municipality Inari, Sales manager	
Customer target price: 140000–160000 €	End-customer, Sales manager	
Sales target price: 150000 €	Sales manager, Product manager	x
Target cost: 100000 € (as pre-designed)	Sales manager, Product manager	x
Target net profitability: 21%	Sales manager, Product manager	x

Figure 5 Construction Object-Related Pre-Design Data and As Required and Pre-Designed BOM Configuration

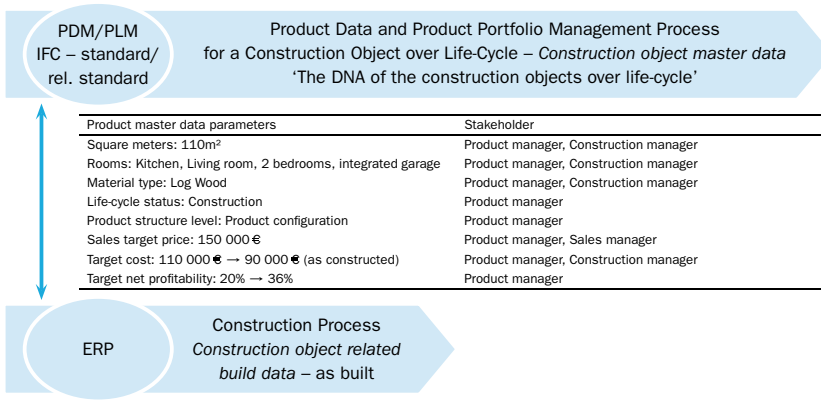


Requirements	Stakeholder	Product master data in PDM
Temperature range: –50°C/+40°C	Product manager, Designer	x
Square meters: 110 m²	Product manager, Architect, Designer, End customer	x
Rooms: Kitchen, Living room, 2 bedrooms, integrated garage	Product manager, Architect, Designer, End Customer	x
Material type: Log Wood	Product manager Architect, Designer	x
Life-cycle status: design	Product manager	x
Product structure level: product configuration	Product manager	x
Design specification: attached PDF file SC A.1 110 D20649.12	Designer	
Construction design for groundwork	Designer	
Heating, Water and Air design	HVAC designer (Heating, ventilation, and air conditioning)	
Sales target price: 150 000 €	Product manager, Sales manager	x
Target cost: 100 000 € → 110 000 € (as designed)	Product manager, designer	x
Target net profitability: 21% → 20%	Product manager	x

Figure 6 Construction Object-Related Design Data and As Designed BOM Configuration

sign parameters and potential stakeholders can be linked to the context.

Figure 7 illustrates the construction process, the related build data and the *as built* BOM configuration. Examples of related product master data parameters are provided together with stakeholder information. The rele-



Product master data parameters	Stakeholder
Square meters: 110m²	Product manager, Construction manager
Rooms: Kitchen, Living room, 2 bedrooms, integrated garage	Product manager, Construction manager
Material type: Log Wood	Product manager, Construction manager
Life-cycle status: Construction	Product manager
Product structure level: Product configuration	Product manager
Sales target price: 150 000 €	Product manager, Sales manager
Target cost: 110 000 € → 90 000 € (as constructed)	Product manager, Construction manager
Target net profitability: 20% → 36%	Product manager

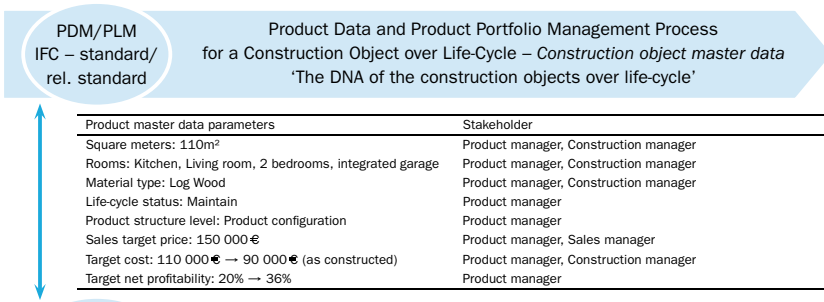
Build parameters	Stakeholder
Building instructions and specification: attached PDF file SC A.1 110 B20649.12	Designer, Construction manager
Building instructions for groundwork	Designer, Construction manager, Ground work sub contractor
Building instructions for Heating, Water and Air	HVAC designer, Construction manager, HVAC-subcontractor

Figure 7 Construction Object-Related Build Data and As Built BOM Configuration

vant build parameters can be linked to the construction process, as well as can the relevant stakeholders. The context is the same log house example. As construction process operational by nature enterprise resource planning (ERP) is logical to be used in the context of the business process. It is possible that BOM master resides in ERP, or in a PDM/PLM system. All the activities should be guided by the product structure, so data can be logically linked to the structure to link the applications and business processes. If master data reside in PDM/PLM, then the master data are copied to ERP.

Figure 8 illustrates the sales process, the related marketing and sales data, and *as marketed and sold* BOM configuration. The context is the same log house example. Examples of related product master data parameters are provided together with stakeholder information. The relevant marketing and sales parameters are linked to the sales process, as well as the relevant stakeholders. Due to the nature of the sales process, a separate customer relationship management system may be necessary. The sales process should be linked to commercial productization and the commercial product portfolio to logically guide the sales process so that sales will include existing and possible/allowed configurations of construction objects.

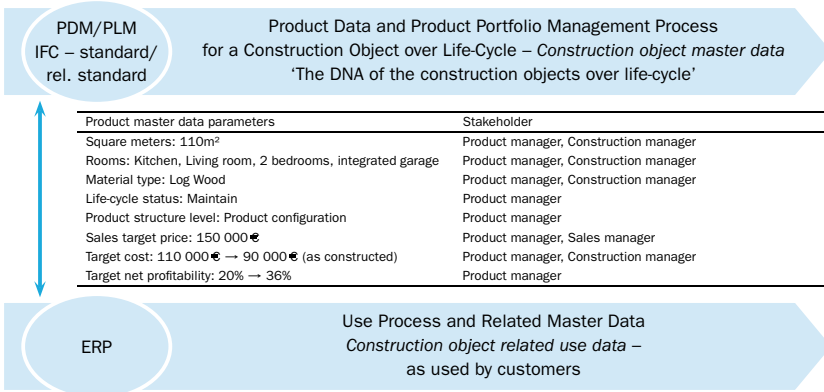
Figure 9 links the construction object-related use process, related master data and the *as used* BOM configuration. Examples of related product master data parameters are provided together with stakeholder information. The living process related parameters and relevant stakeholders can be linked to the context of the same log house example. The company who constructed the log house will have the relevant master data in their data



Product master data parameters	Stakeholder
Square meters: 110m²	Product manager, Construction manager
Rooms: Kitchen, Living room, 2 bedrooms, integrated garage	Product manager, Construction manager
Material type: Log Wood	Product manager, Construction manager
Life-cycle status: Maintain	Product manager
Product structure level: Product configuration	Product manager
Sales target price: 150 000€	Product manager, Sales manager
Target cost: 110 000€ → 90 000€ (as constructed)	Product manager, Construction manager
Target net profitability: 20% → 36%	Product manager

Marketing and sales parameters	Stakeholder
Name of the customer	Sales manager
Customer address	Sales manager
Actual customer price: 170 000€	Sales manager
Rental price: 500€/month	End-customer (owner), Sales manager
Marketing material for Sales partners	Sales manager, Sales partners

Figure 8 Construction Object + Related Marketing and Sales Data and As Marketed and Sold BOM Configuration

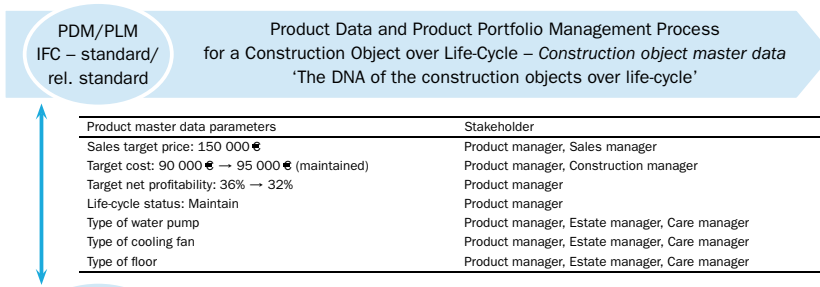


Product master data parameters	Stakeholder
Square meters: 110m²	Product manager, Construction manager
Rooms: Kitchen, Living room, 2 bedrooms, integrated garage	Product manager, Construction manager
Material type: Log Wood	Product manager, Construction manager
Life-cycle status: Maintain	Product manager
Product structure level: Product configuration	Product manager
Sales target price: 150 000€	Product manager, Sales manager
Target cost: 110 000€ → 90 000€ (as constructed)	Product manager, Construction manager
Target net profitability: 20% → 36%	Product manager

Living process related parameters	Stakeholder
Name of the owner	Estate manager, Owner
Address of the owner	Estate manager, Owner
Name of the end-customer	Estate manager, Owner, End-customer
Address of the end-customer	Estate manager, Owner, End-customer
Water consumption	Estate manager, Owner, End-customer
Heating consumption	Estate manager, Owner, End-customer
Rental price	Estate manager, Owner, End-customer

Figure 9 Construction Object Use Process and Related Master Data and As Used BOM Configuration

management system. Use process can be considered as operational so that should the construction company also manage the construction object during the use-phase, ERP is a logical in the context. Should the construc-



Product master data parameters	Stakeholder
Sales target price: 150 000 €	Product manager, Sales manager
Target cost: 90 000 € → 95 000 € (maintained)	Product manager, Construction manager
Target net profitability: 36% → 32%	Product manager
Life-cycle status: Maintain	Product manager
Type of water pump	Product manager, Estate manager, Care manager
Type of cooling fan	Product manager, Estate manager, Care manager
Type of floor	Product manager, Estate manager, Care manager

Service, maintenance and care process related parameters	Stakeholder
Name of water pump service and care sub-contractor	Estate manager, Care manager, Owner
Name of cooling fan service and care sub-contractor	Estate manager, Care manager, Owner

Figure 10 Construction Object Service, Care and Maintenance Process and Related Data and As Maintained BOM Configuration

tion company not be involved during the use-phase, a separate management company and their ERP could be linked into the context in terms of the *as used* BOM configuration to support activities during the use-phase. In case of a private customer, the necessary use-phase data can be provided in a suitable format and can contain information that would not exist without adequate data management.

Figure 10 illustrates construction object-related service, care and maintenance process, related data and links to the *as maintained* BOM configuration. Examples of related product master data parameters are provided together with stakeholder information. The service, care and maintenance process related parameters and relevant stakeholders can be linked to the context of the same log house example. Service, care and maintenance process can be considered operational so that the construction company should also manage the construction object during this phase, ERP is logical in the context. Should the construction company not be involved during the use-phase or be partially involved, a separate management company and their ERP could be linked into the context in terms of the as maintained BOM configuration to support activities during this phase. In case of a private customer, the necessary use maintenance-related data can be provided in a suitable format and can contain information that would not exist without adequate data management. This type of thinking may provide new opportunities and possibilities for efficiency improvement.

Finding 4 *Construction object-related data management may benefit greatly of considering master data, business processes, and BOM configura-*

tions together with related parameters and stakeholders together with linkages to necessary enterprise applications and productization.

Discussion

Construction object-related data management is a topic that is insufficiently addressed by construction companies. It appears that there is a need to better understand master data and business data, and their role to enable effective and meaningful data management in construction. This understanding may further support considering the roles of business processes, enterprise applications and data in construction to improve productivity and enable effective digitalisation.

Construction object-related master data are the data that are created during the design phase. These data are released to be used by other company functions and business processes. Master data are validated at different phases of design process to ensure they meet the needs of the business processes. The quality of master data should not be compromised. Construction object-related business data are product data with business process-related additional data that are needed to perform transactions.

The boundary conditions set by law and building control, as well as the specific nature of the construction industry, should be acknowledged alongside the data management to ensure the optimal meaningfulness of the activities. Productization of the offering, both commercially and technically, is a necessary pre-requisite to ensure a systematic product structure to support data management. The higher-level logic of data management is rarely discussed in the construction context. This logic should involve the construction offering and the related logic, the productization, the data, the business processes, relevant enterprise applications and their roles. The thinking can be taken a step further to acknowledge the BOM configurations and the relevant parameters and stakeholders. This may provide the necessary building blocks towards meaningful digitalisation of the construction industry together with many potential benefits.

Managing the portfolio of construction objects along the life-cycle, and the active analysis over profitability are along the potential benefits. Also, effective configurability and modularity are possible through productization, not to mention configuration management and value chain considerations. The construction objects can be effectively connected to the delivery process. Master data are the glue that holds the variety of considerations together. The true industrialisation of the construction industry and related gains in terms of economy of scale and productivity may become possible.

Finding 5 *Construction object-related data management could be an enabler for the productivity of construction industry.*

Scientific Implications

The scientific implications include highlighting the construction object in the data management context and providing a tangible example that considers master data and business data in the context of product structure, business processes, and enterprise applications. The findings are in line with previous studies by Pinquié et al. (2015), Tolonen et al. (2014), and Harkonen et al. (2017, 2018) in terms of product structure, but provide new discussions in the context of construction objects. This study is particularly in line with Boton et al. (2016) in product structure having a role in organising data. The results also concur with Eynard et al. (2004) in the structure having a role in managing BOMs and product configurations. A new contribution is, however, provided by emphasising the role of commercial product structure that is not commonly covered by the literature in the data context. This study is in line with Hannila, Tolonen, et al. (in press), Svensson and Malmqvist (2002), and Pinquié et al. (2015) in the product structure being transferred to other enterprise applications along updates. The findings also concur with CIMdata (2001) in that PDM/PLM can be used to manage the structure. The application is, however, not very common in the construction industry, as companies have not realised on how to utilise a system that integrates project management to better fit the nature of the business. This indication is a new contribution. ERP is indicated as an alternative. This study is in line with Svensson and Malmqvist (2002) with different needs for views in terms of product structure. A new contribution is provided to the discussion on different views and varying needs by presenting different BOM configurations in the construction context. The related productization discussion by Hemple (2018), Harkonen et al. (2015; 2017; 2018), Tolonen et al. (2018), and Kuula et al. (2018) also provided support by providing a practically relevant example in the construction setting. Master data Discussion by Stark (2011), Aiken and Billings (2013), and Das and Mishra (2011) is supported by presenting an example in the construction context. Authors that have attempted to paint a more comprehensive picture with their specific focus (Hannila, Tolonen, et al., in press; Hannila, Koskien, et al., in press; Silvola et al., 2011, 2019) are complemented by presenting a construction industry specific example. New contribution is, however, provided by indicating some industry specific issues and taking the discussion to parameter and stakeholder levels, while including the product structure in more detail.

The discussion on construction industry productivity by Fulford and Standing (2014), and Pekuri et al. (2011) is supported by indicating new avenues for improving the productivity by the means of better data management. The industrialisation of construction activities (Linner & Bock, 2012)

is supported by providing true means for supporting data management. This may entail design actions by using a set of pre-defined components to benefit also other company activities aside data management, as well as the effective utilisation of product structure and BOM. The findings provide support for Jiao et al. (2013) and some food for thought for avoiding pitfalls of fragmentation into domains of architecture, engineering, construction and facilities management. New ideas are provided by highlighting the roles of product structure and data management. The findings support Cerovsek (2011) in emphasising the importance of possibilities of data being used by other domains. The challenge of the project nature (Bakis et al., 2007) provides solution-oriented support by indicating possibilities of the enterprise application selection.

Overall the new contribution includes linking data, business processes, enterprise applications, productization, product structure concept, necessary parameters, and stakeholders in construction data management context. New contribution is provided by discussing different BOM configurations and data management in the construction industry context. A new contribution might be provided to the construction specific life-cycle discussion. Discussion on business processes and enterprise applications in the data context is supported. Also, the digitalisation discussion in construction setting is supported by providing a meaningful set of building blocks to digitalise effectively.

Managerial Implications

The managerial implications of the study include providing a rather practical example of how construction object-related data management can be considered. The example includes an entity that covers aspects from the very practical level of what master data and business data are to providing a structure for managing data via product structure. The roles of business processes and enterprise applications are also linked to the entity. Different BOM configurations, related parameters and stakeholders are discussed in the context of business processes and product structure. Responsible managers in the construction sector can gain valuable insights with a broader scope for setting up their data management for future competitiveness. The discussed concepts are linked to other valuable concepts, such as product portfolio management, life-cycle management and company analytics that may prove beneficial for tomorrow's profitability and business success. Managers may benefit of the understanding that designing construction objects based on a pre-defined set of components can support avoiding unnecessary business complexity. In other words, one-of-a-kind-components may not always be necessary for standards construction objects, and it is possible to generate architectural value also in other ways.

Limitations and Future Studies

The limitations of this study include considering the data management of construction objects by utilising publicly available material, and not confirming the findings with construction professionals to obtain their feedback. A certain criterion of practicality was utilised. The rather detailed but simple example can, however, prove valuable for construction or any other professionals in related fields. Mandatory design requirements are checked in the context of Finland only, but otherwise the presented concepts are generic. Not including further details on related constructions standards may also be a limitation. Naturally, there are possibilities of organising data management in different ways, but there are no comprehensive descriptions available anywhere in the existing literature for construction objects. Future studies can address the limitations of this study, and include real-life examples in the construction setting, if any are available. The findings can be tested with a random sample of construction professionals to confirm the relevance of the findings. Also, the analytics possible via the product structure and master data may prove an interesting topic for future studies in the construction setting.

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