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Productization of Building Information Models

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Tämä tutkimus esittelee ja määrittelee tämänhetkiset tietomallien tuotteistuskäytännöt ja tarjoaa ratkaisuehdotuksen tietomallien tekniseen ja kaupalliseen tuotteistukseen osaksi rakennusalan tuotevalikoimaa. Työ on tehty perehtymällä kirjallisuuskatsaukseen ja tekemällä nykytila-analyysi valitusta case-yrityksestä. Tämän työn tuloksena suositellaan uuden tietomalli-tuotekategorian perustamista nykyisten rakennusalan tuotevalikoiman fyysisten tuotteiden (HW), ohjelmistotuotteiden (SW) ja palvelutuotteiden (service) rinnalle. Tutkimuksen perusteella tietomallituotteet olisi myös syytä jakaa kaupallisen käytön perusteella kolmeen pääkategoriaan; ilmaiset tietomallituotteet, kaupalliset tietomallituotteet ja tietomallijärjestelmätuotteet. Tietomallien tuoterakenteen muodostamiseen ehdotetaan käytettävän BIM framework-teoriaa, jonka avulla monimuotoisia tietorakenteita on helpompi strukturoida. Tämän tutkimuksen tuloksia voidaan käyttää yleisesti rakennusalalla niin kansallisesti kuin kansainvälisesti. Tutkimuksen tulokset ovat merkittäviä sellaisille organisaatioille, jotka tunnistavat tietomalliensa datasisällön arvon pääomana ja siten haluavat johdonmukaisesti muuttaa heidän tietomalliensa statuksen teknisestä apuvälineestä kaupalliseksi tuotteeksi ja siten osaksi tuoteportfoliotaan.

Muita tietoja

Asiasanat: Tietomallit, tuotteistus, rakennusala

ABSTRACT
FOR THESIS

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Building information models contain a great amount of data in various lifecycle phases throughout building projects. Data is generally not seen as an asset yet building information models' (BIM) value is recognized. Seeing BIM models value as an asset and maintaining a structured product lifecycle management (PLM) in organization leads to need of productization of BIM Models, just like tangible products. Building information modeling is a known term within the building industry, but product lifecycle management is unconventional. Productization practices that include PLM have few examples in the academia or of use in the building industry. This thesis aims to study the possibilities of productizing building information models to commercial and technical items and presents background to it.

Building information models are currently not seen as commercial products, but it is acknowledged they are valuable and have great potential in changing the practices and productivity in the whole building industry. BIM models are not handled as products, and they are not included to order-delivery-invoicing practices and systems as commercial products. BIM models can contain a broad and multidimensional amount of information and some structuring practices of BIM models remind closely of bill of material (BOM) in technical product structures. Information content of BIM models increases and becomes more precise continuously, but to benefit financially of the additional value of BIM models is insufficient in terms of understanding their possibilities in content and commercial value.

This thesis presents the definition and current state of the productization practices of BIM models and offers a recommendation to productize BIM models as a part of construction object configuration commercially and technically. The work is done reviewing current literature and via a current state analysis of a case company. Within the thesis, it is recommended to be establish a new product category into construction product offering alongside to hardware, software, and services: BIM products. From the commercial aspect, it is recommended to divide BIM models into three categories based on their status in a commercial product portfolio: open BIM models, BIM model products and BIM model systems. The recommendations of building a BIM model product structure are based on a BIM framework theory, which allows to separate the broad and multidimensional information structures of BIM models in structured and understandable form. The results of this study can be generalized and used in the building industry internationally. The results of this thesis are significant for any organization wanting to change their building information models' status from technical tools into commercial products in a structured way.

Additional Information

Keywords: BIM models, productizing, construction industry

FOREWORDS

The goal of this thesis was to research the possibilities to productize building information models as part of product portfolio as commercial and technical items. Initiative for the work topic came from the case company interests to productize commercially configurable BIM models. The kick-off for the work was in november 2020 and the finalization in august 2021. Supervisor of the thesis on behalf of university was professor Harri Haapasalo and from behalf of the case company PhD Arto Tolonen. Harri and Arto were a hilarious comedy duo – yet extremely professional combination of supervisors giving on point advices from different perspectives to advance the study. I want to thank both of the joyrney and for making this thesis' process start and end. In addition of being a supervisor, Arto was also a mentor, a person to push the thesis forward and an important shoulder during the journey. And as in each academic work – nothing could happen without a proper peer suppor group: big thanks goes to my fellow master's thesis students Juho, Ilari, Ville and others with whom I was able to share all the moments of despair, joy and most importanly: celebration.

"The road goes ever on and on down from the door were it all began." Never could I have imagined writing second master's thesis in technology, not to mention only five years after the first one. But as the saying goes: life is full of suprises.

Oulu, 1.9.2021 Reetta Lassila

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LIST OF ABBREVIATIONS AND SYMBOLS

AIA	American Institute of Architects
AECO	Architectural, Engineering, Construction and Operations
ATO	Assemble-to-order
BIM	Building Information Model, Building Information Modeling
BOM	Bill of Materials
CMAR	Construction Manager at Risk
CRM	Customer Relationship Management
DB	Design-Build
DBB	Design-Bid-Build
ERP	Enterprise Resource Planning
ETO	Engineer-to-order
FM	Facility Management
IFC	Industry Foundation Classification
IPR	Integrated Project delivery
HW	Hardware
LOD	Level of development, Level of Detail
MET	Model element table
MTO	Make-to-order
NPD	New Product Development
OFP	Order fulfillment process
PDM	Product Data Management
PPM	Product Portfolio Management
PLM	Product Lifecycle Management
SCM	Supply Chain Management
SW	Software

1 INTRODUCTION

1.1 Background

Data is power, isn’t it? In building industry, building information models are used every day, storing huge amount of building related data of various building lifecycle phases. They have broad and multidimensional knowledge structures serving various stakeholders and use-cases (Succar, 2009). Still, BIM has a surrounding mystification, and construction industry has not been able to implement it, nor academia support its utilization (Mansoori & Haapasalo, 2021). The extent of change that is caused or enabled by BIM is not fully understood by the construction industry (Mansoori & Haapasalo, 2021). Generally, BIM is mostly treated as design tool, an extension to the old-fashioned drawing tools, and their potential is not fully understood from the commercial aspect. BIM Models alongside data in them are not seen as an asset. Data in general is not seen as an asset, when again tangible items are. In most sectors, data tends to be seen only as descriptive information about the state of actual assets for the companies, not as an asset itself. Still, the leaders in Big Data instead regard data as an asset in and of itself (Perrons & Jensen, 2015).

Seeing BIM models’ value as an asset and maintaining a structured PLM in organization leads to need of productization of BIM Models, just like tangible products. The concept of productization and the relationship of modelling of products and services has been discussed only to some extent even though productization has a remarkable importance for effective productization of construction companies’ offering (Härkönen *et al.*, 2018). According to Mansoori *et al.* (2021) applying the productization concept would help to improve the BIM implementation, help ensure process fluency and product data integrity among systems.

1.2 Research objective, questions, and scope

This thesis focuses on helping organizations within building industry to see and understand their possibilities with BIM models as a data asset by finding a solution to productize BIM models as a part of supply chain and Product Lifecycle Management. This is done by defining the current state of the productization practices of BIM models based on literature and by analyzing the current state of productizing them in building industry by means of a case study. The results of this thesis aim to offer a solution to productize BIM models as part of construction object configuration commercially and technically to change BIM models' status form technical tools into commercial products in a structured way.

Productizing building information models requires a closer look into the current productization practices in the building industry and productization practices related to building information models, which is done in this thesis with the following research questions:

1. How is the productization of building information models (BIM) defined in earlier research?
2. What is the current state of productization of building information models in the case company?
3. How to productize BIM as a part of construction object configuration commercially and technically?

Literature review of this work focuses on the first research question, current state analysis to the second research question and results chapter focuses on the third research question, as shown in the **Figure 1.**

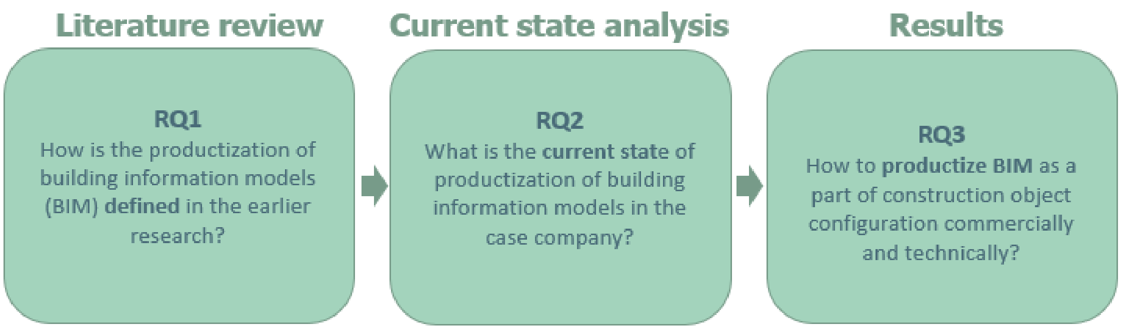

Figure 1. Research questions and their phases in the study

Within this thesis, the terms **construction industry**, **building industry** and **Architectural, Engineering, Construction and Operations (AECO) industry** are used interchangeably. The scope of the thesis is limited to the field of building construction and encompasses the whole delivery process from new product development to design, completion, and operation. The areas explored cover the lifecycle of a building: sales, pre-design, design, fabrication, site assembly and operation. Illustration of the aspects and limitations of the study are shown in the **Figure 2**, in which grey areas are left out of the scope of the study and colored parts are focused more thoroughly. The thesis does not focus on any specific process but in the lifecycle of a building in general. Also, product data management viewpoint, including design, manufacturing and service phases, is explored only at a general level without focusing on any specific phase. The product portfolio is examined both from technical and commercial side, but the results focus only on the commercial side to support the concept of data being an asset. Also, the scope of the order-fullfilment process and invoicing is limited to a general level, not focusing on any specific part of it. The aim of this is to explain the supply chain dependencies of commercial product items. Thus, pricing is handled in the extent of what is needed to show the value of BIM models and the principles of pricing at a very general level. Pricing is considered only in theory and detailed pricing is left out from the results. The limitations also exclude product lifecycle management activities such as product management and product portfolio management.

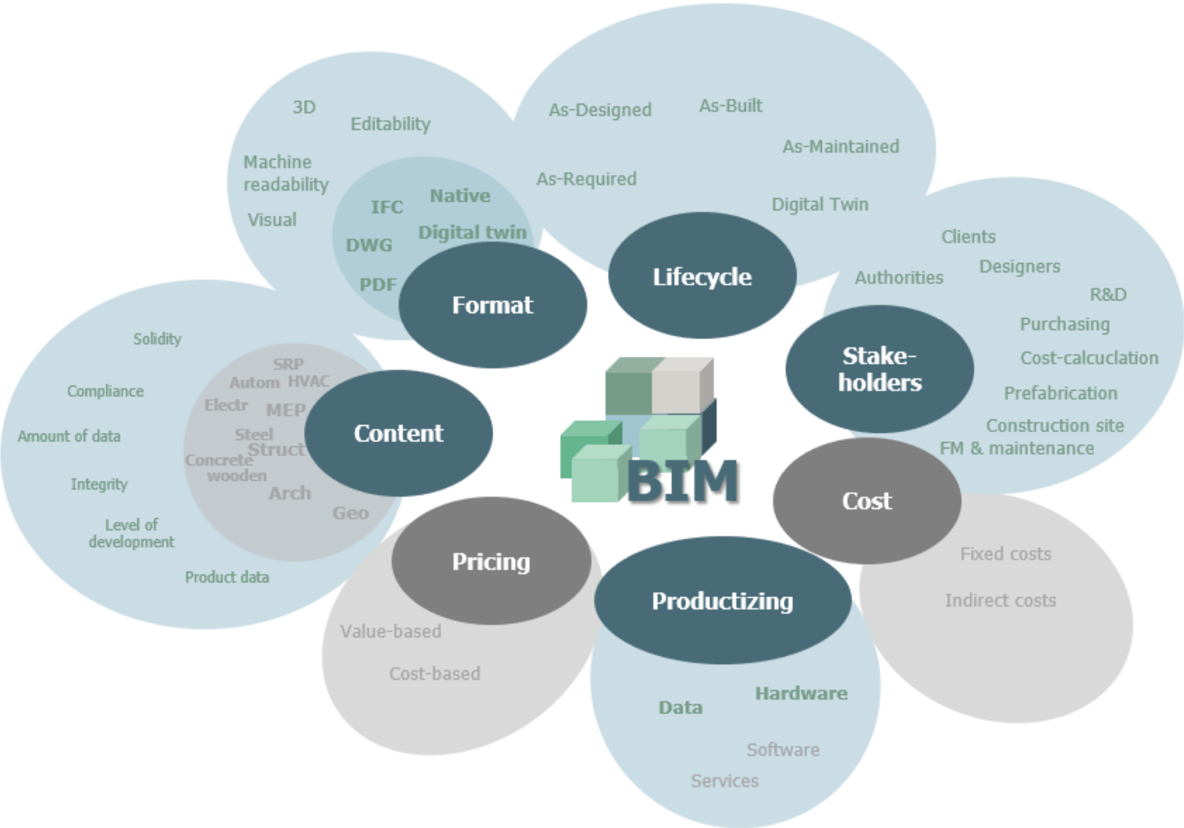

Figure 2. The viewpoints of productizing Building Information Models

The use of the term **building information model**, also referred as **BIM model**, is also limited to the context of building industry. The scope of Building information models is kept at a general level, not focusing on any specific design fields, technicalities of programs nor any information within BIM models. The scope of the productization practices is limited in the general level productization of hardware products, emphasizing more on the commercial configuration. These limitations exclude all the technicalities of the assembly, sub-assembly, version, and variant levels of technical product offerings. Within this study, the term product refers to Kropsu-Vehkaperä's (2012) definition of a product and later Tolonen's (2016) additions to definition, that are presented in chapter 2.1, in the literature review of this study. The findings of this study focus on single construction company however, the selected company pursues strongly towards achieving industrialized operational model, and thus gives better starting point in productization.

1.3 Research process

Research questions are divided to literature review, current state analysis and results as presented in **Figure 1**. The first research question is answered in the literature review, second in the current state analysis and the third in the recommendations. Current state analysis is based on the case company study that includes quantitative data analysis of building information model data and structured interviews of selected people in the organization. The case company in the research is a large Finnish construction and real estate company.

First, the research focuses on the literature review of the core topics of product and productization, and the related practices in construction industry. Also order fulfillment process in construction industry is studied. Finally, the literature review focuses on introducing building information models, and them in the contexts of product and their part in order fulfillment process. In the current state analysis phase, literature review findings are used and compared to the findings of the case analysis. In the results chapter, the conclusions are presented based on the theory and current state analysis, and recommendations and outcome are given.

2 LITERATURE REVIEW

2.1 Concepts of product and productization

2.1.1 Product and productization definition

Product definition

Product has a traditional definition of a tangible physical entity that can be bought or sold (Liu *et al.*, 2009). Still, the definition has extended further alongside enterprise environment changes (Liu *et al.*, 2009). Literature defines a product in various ways, and it has various meanings (Kropsu-Vehkaperä, 2012; Peltonen, 2000). Kropsu-Vehkaperä (2012) defines product as "*hardware (HW), software (SW), services or a combination of some of them,"* that is a part of a portfolio and not an individual serial-numbered item. Kropsu-Vehkaperä (2012) also states, that informational aspects of products are becoming more critical as business processes are relying increasingly on information systems.

Most recently, Tolonen (2016) has defined product to be both commercial and technical item that appears in product portfolio management (PPM) framework. PPM portfolios are categorized vertically to commercial and technical, into which the products, that are a horizontal part of the portfolio, are divided. In commercial portfolio the products are items that are visible to customer and can be "*ordered, delivered and invoiced*." In technical portfolio the products consist of technical items. (Tolonen 2016). Products go through various phases during their lifecycle. Lifecycle of a product can be observed from may viewpoints: marketing & sales, product management, new product development and data management (Mustonen, 2020).

Productization definition

In context of productization, a product must be defined from the marketing and sales point of view, when it means something *"that is sold by an enterprise to its customers"* (Hänninen *et al.*, 2012). Productization as a term is quite new, it has many definitions in the literature, but there is no generally accepted definition for it (Mustonen, 2020; Suominen, 2009; Hänninen *et al.*, 2012). Productization is mostly described as a process, extent of which varies (Mustonen, 2020). In the literature, productization is described as a representation of the company's know-how in a "*defined, clear and easily purchased* *solution for a customer's problem"* that aims to *"package an offering, technology or service in a way that the customer can understand the content in advance"* (Hänninen *et al.*, 2012). It is also stated to be a "*process of analyzing a need, defining and combining suitable elements, tangible and intangible, into a product-like object, which is standardized, repeatable and comprehendible"* (Härkönen *et al.*, 2015). The definition from the product portfolio point of view describes productization as "*defining a company's products to gain a consistent understanding of what the company's product portfolio consists of"* (Mustonen, 2020).

"The act of modifying something to become a commercial product" (Hänninen *et al.*, 2012) is the basic idea of the productization that fits to all the above presented definitions from the literature. The activities of productization slightly vary depending on the definition of the productization used. It can be for example a set of activities from the market opportunity perception until the production, sales & delivery of a product that aim to modify the company capabilities and know-how to meet customer requirements. In this definition, the precise activities are defining, specifying, and profiling of products (Hänninen *et al.*, 2012). Härkönen *et al.* (2015) add that it can also be activities which aim product to be commercially ready, so that it can be produced, delivered, purchased, and used.

The focus and activities of productization are different regarding on which product type is produced; HW, SW or service. Productization of technology focuses on "*gaining market success by converting technologies into products"* and is strongly linked to commercialization. Hence, both technical and commercial aspect of a product need to be acknowledged in productization. (Mustonen, 2020). This is proposed to be possible by utilizing the generic concept of product structure, where both commercial and technical aspects of a product are identified. This productization logic helps "*to clarify and tanglibilise the offering for sales, delivery and invoicing"* by enabling the configuration of the elements in commercial portfolio and the modularity in technical portfolio. (Mustonen, 2020; Härkönen *et al.*, 2017).

In productization new products are tried to be developed to customers, which means, that definitions of a product development (NPD) and productization are quite close to each other. Still, the definition's major difference is that product development starts from idea creation and tries to reach to production, sales and delivery, meanwhile productization focuses on defining and describing company's products. (Mustonen, 2020).

Product structure concept

Product may consist of single piece or several parts and components (Mustonen, 2020). Product structure is a combination and presentation of the product itself, information linked to it and relationships between product parts (Kropsu-Vehkaperä *et al*., 2011). Product structure itself consists of parts, components, assemblies, and documents (Sääksvuori & Immonen, 2008), and the structure depends on the product type (Mustonen 2020). The structure is proposed to model products vertically (Kropsu-Vehkaperä *et al*., 2011) and the number of product structure levels depends on the complexity of products (Tolonen *et al*., 2014).

Clear product structure and the levels of the structure should be defined (Mustonen, 2020; Tolonen *et al*., 2014) to unify and realize products and help in data consistency (Mustonen, 2020). Tolonen *et al*. (2014) present a model of product structure of commercial levels (solution, product families, product configurations and sales items) that are visible to customers, and technical levels (version items, assemblies, sub-assemblies, and components) that are visible to company (Mustonen, 2020). This product structure model is presented in **Figure 3**. A product structure contains components that are interchangeable and configurable, through which the product can be customized for customer specific product configuration (Mustonen, 2020).

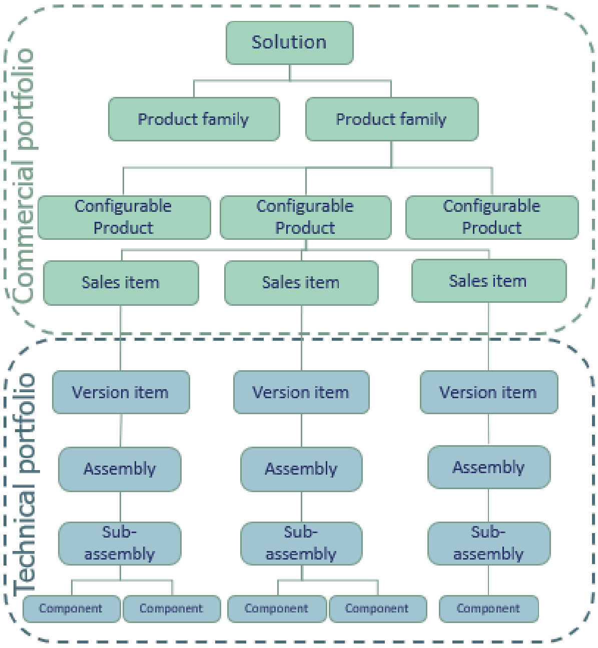

Figure 3. Product structure levels and product portfolios modified from Mustonen (2020) and Tolonen (2014).

Product variants and versions

Different product variants are made to satisfy different customer requirements. They broaden the number of deliverable sales items, and they exist in parallel. Product variants are alternatives of which the final deliverable can be chosen. (Kropsu-Vehkaperä, 2012; Seppänen, 2016; Mustonen, 2020). Product versions are used in the technical side of the productization to define new technical updates to assemblies or components that are not visible to the customer (Kaukua, 2016).

2.1.2 Product Data Management

Productization and dividing product structure into commercial and technical part are not only linked but also support each other. Productization alongside with product structure can lead to consistent and fact-based analysis of products. It is highly important to understand company products in their commercial and technical structures to make fact-based analysis of the variety of products. The traditional understanding of technical product structure is not sufficient (Härkönen *et al.*, 2019). Product portfolio management (PPM) provides necessary understanding of the company's products, and thus productization is closely related to PPM (Mustonen, 2020).

Data is a strategic asset but not fully capitalized to serve business. Companies may have applications for example for design, enterprise resource planning (ERP), and customer relationship management (CRM). Mostly product master data, the most important data, is stored in product data management system (PDM) (Härkönen *et al.*, 2019; Silvola, 2018). This master data must be reliable and unaltered (Härkönen *et al.*, 2019). PDM is a separate software or a collection of them used to control and track data related to a certain product (Silvola, 2018). It is normally part of the product lifecycle management strategy (PLM), but also configuration management and used by engineers. The technical product structure and its master data may be in PDM or in ERP based on the company logic (Härkönen *et al.*, 2019). Bill of materials (BOM) structure of the products is often stored in PDM-systems (Härkönen *et al.*, 2019).

According to the definition of a product presented earlier, customer products need to be ordered, delivered, and invoiced (Tolonen, 2016). To be able to order, deliver and invoice certain product, product master data must remain unaltered through product data management process. In this process product data is kept in PDM systems and other product related business data in their specific systems; sales data in CRM, Supply Chain process related product data in ERP/MES or CAM and service and care related product data in ERP and service / care applications (Silvola, 2018). The logic of the product data flow is presented in **Figure 4**.

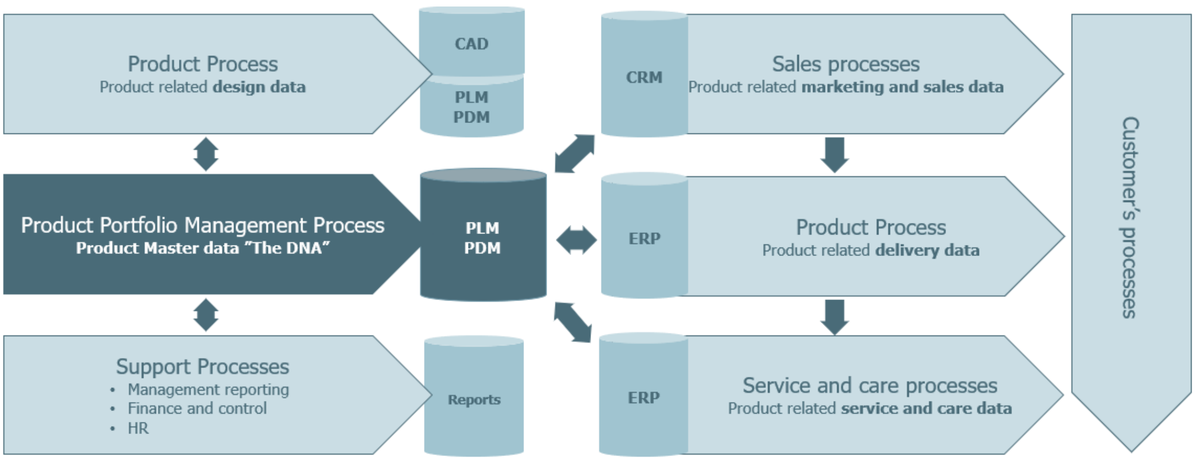

Figure 4. Product data flows in order-delivery-invoicing processes modified from Silvola (2018)

2.1.3 Technical productization

Technical productizing provides technical version items, assemblies, sub-assemblies, and components that are used in creating and delivering the sellable items as presented in **Figure 5**. Based on the product structure concept, technical productization's focus is on "*defining, clarifying and tangibilising the deliverable offering",* and it concentrates on modularity. (Mustonen, 2020; Härkönen *et al*., 2017; Tolonen 2016).

Bill of materials (BOM) is an unstructured manufacturing part list, but it is closely related term to product structure (Mustonen, 2020; Sääksvuori & Immonen, 2008). Different BOM's are created over the product lifecycle for the purposes of different stakeholders (Tekin, 2015; Mustonen, 2020). The most important ones are Engineering BOM (EBOM) in as designed-phase and Manufacturing BOM (MBOM) in as-built phase (Mansoori *et al*., 2021; Mustonen, 2020). Also, the maintenance bill-of materials should be taken into consideration when operating in maintenance-phase (Mustonen, 2020; Liu *et al*., 2014). There is a close relationship between EBOM and MBOM: EBOM is usually generated in CAD and it represents the engineering viewpoint where items are listed according to parent product's assembly drawings. MBOM represents the manufacturing viewpoint and is generated by human based on EBOM and adding some manufacturing information (Mustonen, 2020).

Companies use certain production strategy for their product manufacturing, that affects the cost distribution of the product. These strategies are generally referred as order-fulfillment strategies The typical strategies are e.g., made-to-order (MTO), made-to-stock (MTS), assemble-to-order (ATO) and engineer-to-order (ETO) or combination of these. MTO is tailored and meets the demand right away, while MTS has low variety and responds demand through finished products inventory. ETO is the most tailored of these and has most variation in products. (Rabbani *et al*., 2014; Cameron *et al*., 2004; Barbosa *et al*., 2018, Pil *et al*., 2004).

Härkönen *et al*. (2019) state, that the traditional thinking of technical product structure is not sufficient. In their study, it was commonly not clear for the analyzed companies which element should be considered as the part of the product, neither had they total understanding of how their products were productized. The role of BOM was understood, but the logic between products and business lines was inconsistent. Thus, the product has to be considered as both technical and commercial item as it combines the perspectives of sales and cost structure of the products. (Härkönen *et al.,* 2019)

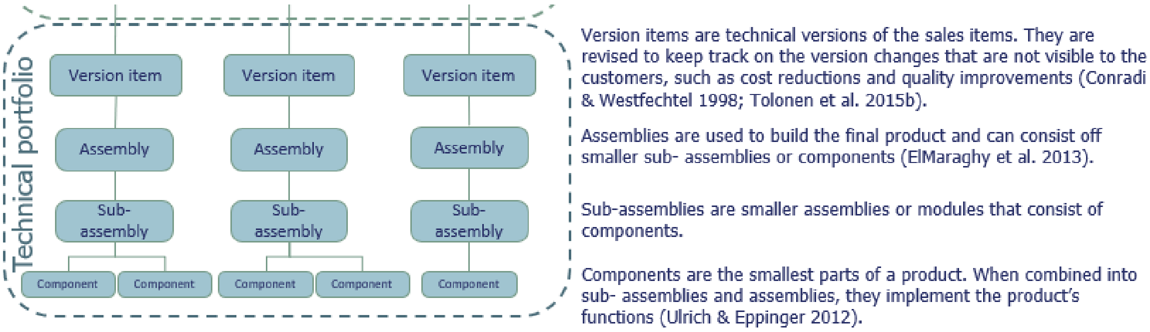

Figure 5. Technical portfolio and product structure modified from Mustonen (2020) and Tolonen (2014).

2.1.4 Commercial productization

Commercial productizing provides the sales view of the product offering individual sales items that are configurated from configuration elements such as variants and options. Based on the product structure concept, the focus is on "*defining, clarifying and tangibilising the sellable offering"* and it concentrates on commercial configurability. (Mustonen, 2020, 36). Commercial product portfolio consists of solution, product families, configurable products, and sales items (Härkönen *et al*., 2019; Mustonen, 2020; Tolonen *et al*., 2014) as presented in **Figure 6**.

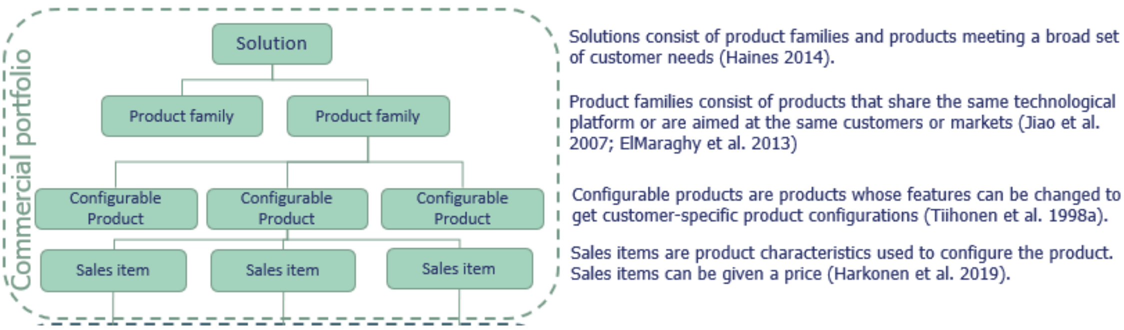

Figure 6. Commercial product portfolio and product structure levels modified from Mustonen (2020) and Tolonen (2014).

In the commercial aspect, price is an important element. Marketing mix is a model that defines marketing tools (Quelch & Jocz, 2008), and price of a product is the only element in the marketing mix that is producing revenue while all the other elements are representing costs. In the minimum, price can mean the amount of money that is charged for a product, but in the maximum, it is the sum of all the values that customers are ready to give up gaining the benefits of having or using the product (Kotler & Armstrong, 2016). In industrial markets, there are three main approaches to pricing: cost-based, competition-based, and value-based approach. Value-based approach is considered superior by research, but only a few industrial companies have adopted it (Kotler & Armstrong, 2016; Liozu & Hinterhuber, 2012). Value-based pricing does not directly mean setting low prices or charging what customer wants to pay. It can include value-added pricing strategies in which value is added for example by features and services and thus support higher prices. In cost-based pricing, the minimum price is set based on costs for producing, distributing, and selling the product (Kotler & Armstrong, 2016). The models of value- and cost-based pricing are presented in **Figure 7**.

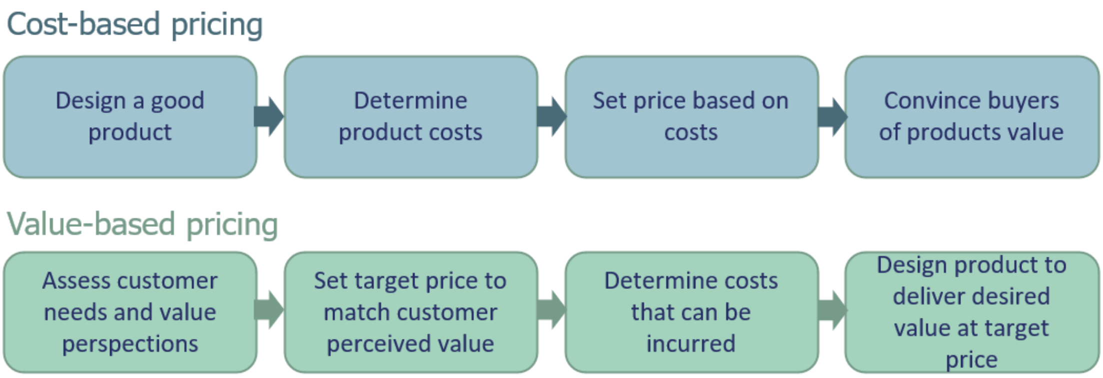

Figure 7. Cost-based pricing and value-based pricing models modified from Kotler & Armstrong (2016)

2.2 Current productization practices in Building Industry

2.2.1 Product and productization definition

Product

In the construction industry, the product is typically seen as a completed facility (Mansoori *et al*., 2021; Härkönen, 2018; Maloney, 2002). Mansoori *et al*. (2021) studied for example the product definition in construction industries, and research showed, that mostly product was defined as building, but also each building block and building element could be understood as products. Products were seen something non-service-related in Mansoori *et al*.'s study (2021). Still, on top of the physical product, contractors provide services (Härkönen *et al.*, 2018; Maloney, 2002). Product configurability has been considered as a product family type with systems and subsystems, but service products in this context has not been discussed (Härkönen *et al*. 2018).

At some contexts, building information models (BIM) are referred as product models (Cerovsek, 2011), also in the current literature BIM models are defined to be products in construction industry, but the product is not digitally defined in the design (Mansoori & Haapasalo, 2021). BIM has also many legal unclarities concerning the ownership of the collaborative BIM models (Smilow, 2007; Gray *et al*., 2013; Haron *et al*., 2009). Technology and science are developing faster than intellectual property right (IPR) legislation and it has led to use of BIM products IPR according to general rules (Stepanenko, 2019). BIM products may include several objects that are regulated by different laws since the law doesn't recognize the concept of BIM product. To legally protect the BIM product, forms of it needs to be regulated. BIM products may include several IPR based on different laws such as databases, design solutions and know-how (Stepanenko, 2019).

Productization

Concept of productization has been studied only a little in the construction context (Mansoori *et al*.; 2021, Härkönen *et al*., 2018). Productization was characterized as "*an ongoing process based on the construction business"* by the interviewees in Mansoori *et al*.'s (2021) study. The concept of productization and the relationship of modelling of products and services has been discussed only to some extent even though productization has a remarkable importance for effective productization of construction companies' offering (Härkönen *et al*., 2018). According to Mansoori *et al*. (2021) applying the productization concept would help to improve the BIM implementation, help ensure process fluency and product data integrity among systems. Product structure is seen important in adapting BIM in building processes (Härkönen *et al*., 2018). Mansoori *et al*. (2021) offer a concept of product structure framework and a systematic view to productization definition in construction, that includes input, process, and output. Product structure (PS) framework is introduced in the study to support productization in construction industry (Mansoori *et al*., 2021). The PS framework focuses on filling the current gaps in BIM and productization in construction. The part-phase-element matrix logic in product structure framework is presented in **Figure 8**.

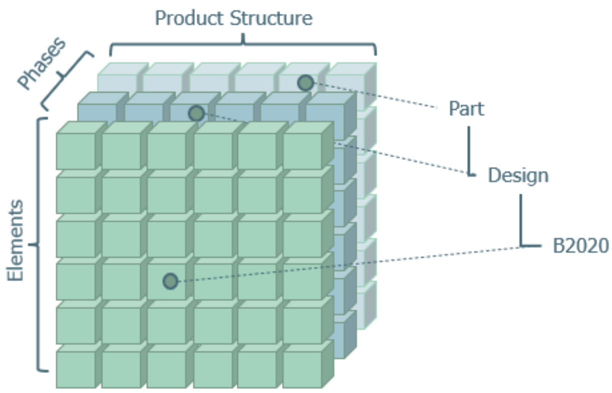

Figure 8. Product structure framework to construction industry: The part-phase-element matrix modified from (Mansoori *et al.*, 2021)

Product structure

The product structure is not studied much in the context of the construction industry. Still, it is argued that the link between standardized product structure would be the missing link to BIM approach, in which the full potential could not have been taken in use (Mansoori *et al.*, 2021). According to Chu *et al.*, (2009) the general product structure involves tasks such as arranging functional elements, mapping them to physical components and defining interfaces of components and technical objects. In construction industry, it has been recognized the potential of technical objects that facilitate exchange of information. Many feature templates have been proposed to predefine database contents in CAD systems, but they lack the appropriate classification. (Mansoori *et al.*, 2021, Chris *et al.*, 2013).

For product portfolios, with commercial and technical items, neither configurability nor modularity have been discussed together in the context of the construction industry. (Härkönen *et al.*, 2018). Product structure can also help in configuration and modularity perspectives (Härkönen *et al.*, 2018; Boton *et al.*, 2018), and BIM models may play critical structuring backbone in it (Boton *et al.*, 2018).

2.2.2 Product Data Management

Product data management has little attention in the construction industry, unlike in other industries, where product lifecycle management has an essential role in business

(Halttula, 2020). The term product data, product data management and product lifecycle management are unfamiliar terms in construction industry (Halttula, 2020). The description of product data in a project is needed to gain the benefits of building information models (BIM) (Halttula, 2020). It is argued in the latest studies that a product viewpoint is the starting point of implementing and utilizing BIM successfully (Mansoori & Haapasalo, 2021).

2.2.3 Technical productization

Productization makes the construction offering more systematic and tangible and the maximization of construction activities is supported through commercial and technical modelling (Härkönen *et al*., 2018). In the construction industry, the Model Element Table (MET) is used to define the information requirements in BIM. MET is quite like BOM in the manufacturing industries. In the MET, the model elements and level of development (LOD) is listed to each model element author. (Boton *et al*., 2018; AEA 2008). Bill of Materials is argued to be the missing link between existing, but disconnected processes in construction (Boton *et al*., 2018; Härkönen *et al*. 2018).

2.2.4 Commercial productization

Construction companies typically have not modelled the commercial side of their offering, but the construction products and services can be modelled to certain extent with the help of public information (Härkönen *et al*., 2018). Härkönen *et al*. modelled an example of commercial and technical portfolio of construction offering as a product, that includes both product and service point of view. The pricing of the products was not included. (Härkönen *et al*., 2018).

2.3 Order-delivery-invoicing practices in Building industry

2.3.1 Order fulfilment process and invoicing definitions

Order fulfilment process (OFP) is one of the eight supply chain management processes, but it is the key process in the sense that customer's order triggers the other supply chain activities in motion. Order fulfilment "*involves generating, filling, delivering and servicing customer orders*" (Croxton, 2003). It includes all the activities from the moment the customer makes the purchase until the product is delivered to the customer (Nguyen *et al*., 2018). The OFP according to Croxton (2003) is presented in the **Figure 9**. Order fulfilment is generally seen as transactional and mainly part of the logistics function in the firm. Still, it is important that its strategic components and cross-functional needs are recognized by managers (Croxton, 2003). Invoicing process again is an important part of a wider set of business processes including the placing and acceptance of an order, delivery, and payment (Spanic *et al*., 2011) To enable an effective ability to sell, deliver and invoice, the product offering needs to be well structured (Mustonen *et al*., 2019).

In the order fulfilment process, the order information is critical. Errors in entering and receiving the order can be costly. Also, all the needs for editing and translating the order to company's system may be costly. Unreliable order information makes the order unreliable for the supplier and thus must be compensated by expensive buffers. (Croxton, 2003; Forslund, 2007) Also, the post-delivery activities are time-consuming. Reducing this work in the firm, the total cost of delivery will be reduced (Croxton, 2003). Building products to customer order and the company's accurate understanding of precise customer configurations decreases reconfiguration in order-to-delivery process and is valuable to a company. Information flow both from customers to the factory and to firm's order-to-delivery capabilities to the customer is important. (Lawson *et al*., 2017).

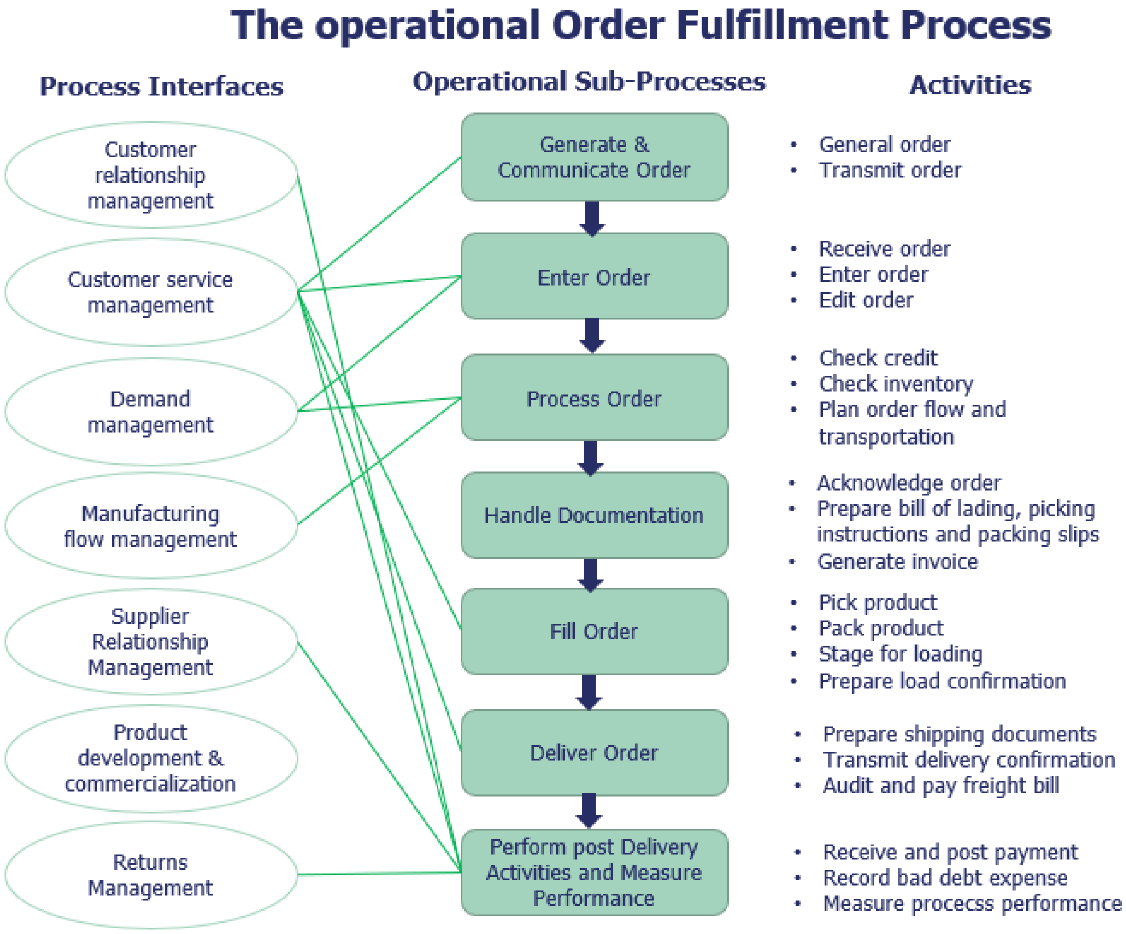

Figure 9. The order fulfillment process theory modified from Croxton (2003)

2.3.2 Order fulfilment process and invoicing practices in Building industry

Construction industry is not continuous like manufacturing industries, and thus, it is called a fragmented industry (Shabani & Nik-Bakht, 2021; Sholeh & Suwarto, 2020).Construction supply chain management is integrated method during the whole project that involves the stakeholders (*owner, consultant, contractor, subcontractor, and supplier)* in the construction project for the success of the project (Sholeh & Suwarto, 2020). According to Grenzfurtner *et al.* (2020) in the construction industry, the subsequent design of components plays one of the pivotal roles in order fulfilment process, unlike in manufacturing industries, where most cases the design process plays the secondary role in OFP. In the project-oriented construction industry, the order-fulfilment-process has project-based focus (Grenzfurtner *et al.*, 2020) and there is no natural demand for the construction product, but the demand is always derived from the demand for the intended facility (Maloney, 2002). The OFP based on Grenzfurtner *et al.* (2020) in industrialized housebuilding industry is presented in **Figure 10**.

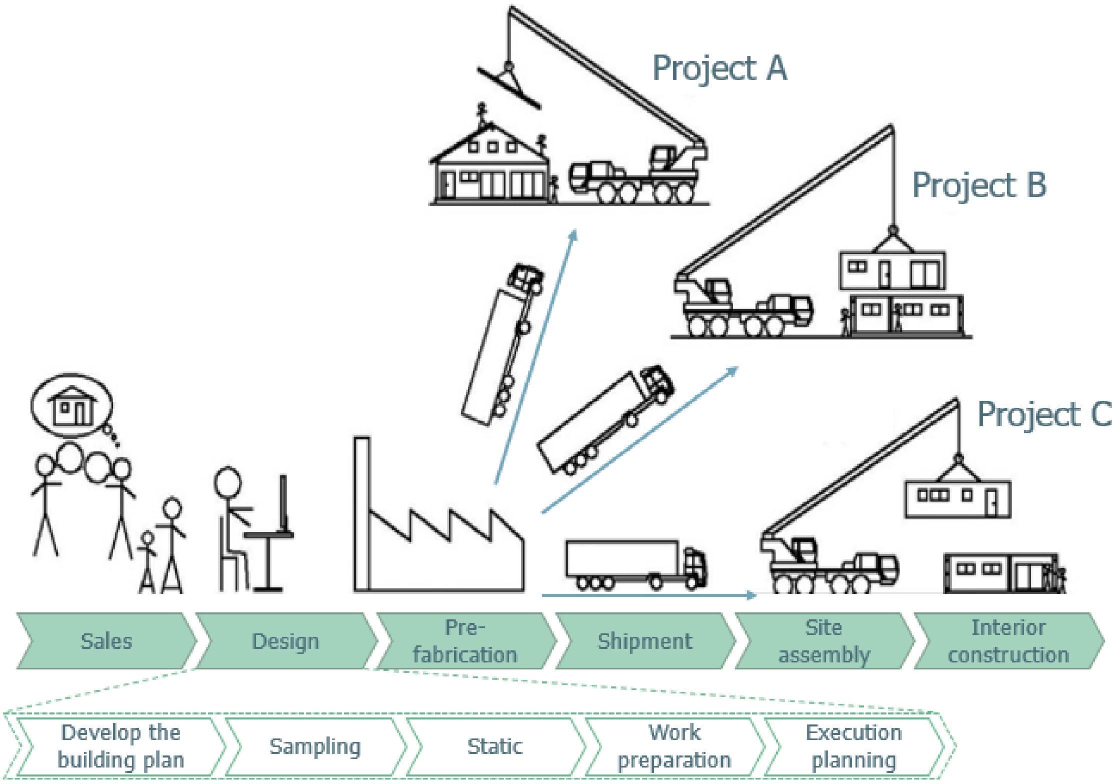

Figure 10. The order fulfillment process in industrialized building industry modified from Grenzfurtner *et al.* (2020)

There are different types of delivery methods and contract types to answer the order fulfilment. The most common delivery methods are design-bid-build (DBB), design-build (DB), construction manager at risk (CMAR) and integrated project delivery (IPR). When providing a physical product, the contractor provides a service that consists of three elements: service product, service environment and service delivery. The service product in this context is the design to be delivered, the service product includes all the additional features that customer gets alongside with the physical product. The service environment is the service provider's internal environment and that of the external environment. Service delivery includes the performance of each role related to the project. (Maloney, 2002)

In construction industry, the customer orders are handled by salesman, who finds out the specific requirements of the customer. After selling the building, the order is processed. After this comes a OFP's subsequent design activities, which are made by multiple internal and external engineers. The design is made to fulfill the unique demands of customers and other requirements. These are divided to conceptual designs and to building component designs. Conceptual design begins already during the sales process.

After the construction plans are completed, the production dates of prefabricated elements are fixed. They are transported to site and finally assembled. After construction, the interior fitting is done and finalized building handed to customer. This kind of a OFP is complex, and thus, it is difficult for everybody to get a holistic overview of it. (Grenzfurtner *et al.*2020).

Construction industry invoicing procedures are progress payment based, and these payment practices are known to be poor worldwide and progress payment is stated to be one of two key causes for delays and overrun in construction projects (Maloney, 2002, Ahmadisheykhsarmast *et al.*, 2020). Progress payment is a bill to the client in exchange of the materials or services delivered (Maloney, 2002). It is partial payment of the work that has been completed during a certain period and is used through a cascade system down the chain (Ahmadisheykhsarmast *et al.*, 2020).

2.4 Building Information Models in Building Industry

2.4.1 Definition of BIM

Eastman *et al.* (2011) defines BIM as both modeling technology and associated set of processes to communicate, analyze and produce building models. For Eastman *et al.* the acronym BIM refers to "Building Information Modeling", that reflects and emphasizes the process aspects, not "Building Information Model" (Eastman *et al.*, 2011). Building information model (BIM model) is the result of building information modeling (AGC, 2006) meaning BIM Process produces objects that are building models or BIM models (Eastman *et al.*, 2011).

According to International Standards Organization (ISO29481- 1, 2016) BIM is a "*shared digital representation of a built object to facilitate design, construction and operation processes to form a reliable basis for decisions*". Succar (2020) defines BIM as a collection of interacting processes, policies, and technologies. It is also described as a "*methodology to manage the essential building design and project data in digital format throughout the building's life-cycle*" (Succar, 2020; Penttilä 2006). Cerovsek (2011) and Halttula (2020) define BIM as a building information model that is a digital representation of an actual building, that has parametric rules that control how model behaves and how the attribute data is modified. According Halttula (2020) BIM can be seen as a process, tool, or a combination of them. BIM can restore geometric and rich semantic information of building models and their relationships to support lifecycle data sharing (Gao *et al*., 2015). Building information modeling can be seen as the use and development of computer software model to simulate facility's construction and operation (AGC 2006).

BIM has a surrounding mystification, and the construction industry has not been able to implement it, nor academia support its utilization (Mansoori & Haapasalo, 2021). The extent of change that is caused or enabled by BIM is not understood by the construction industry (Mansoori & Haapasalo, 2021).The industry is conservative and evolves slowly, and the full use of BIM needs structural changes at business level (Mansoori & Haapasalo, 2021).

2.4.2 Productization related aspects of BIM

BIM as product model

Building Information Modelling (BIM) was previously referred as Building Product Modelling (BPM) (Cerovsek 2011, Halttula 2020). Building product model was defined as the total sum of information of building (Cerovsek, 2011) and building product modeling or product data modeling is a methodology managing essential building design and project data in digital format throughout the building's life cycle (Penttilä, 2006). It is also said that BIM is a product data model of the project that is essential to design lifecycle (Halttula, 2020). Still, such concept as BIM product is not recognized in the legislation (Stepanenko, 2019).

BIM product may include several objects and is used to refer available BIM resources in building product libraries (Stepanenko, 2019; Gao *et al*., 2015). These building product libraries mean typically online BIM resources that contain BIM models associated with product documents such as specifications and descriptions of the objective products (Gao *et al*., 2015). These models are in their native format, that is dependent on the various software vendors (Gao *et al*., 2015). BIM models are not clearly done from the perspective of product structure, but it can be built in (Härkönen *et al*., 2018). Currently, based on Mansoori *et al*, (2021) BIM is lacking well-designed transactional structure.

Product Data Management and Building Information Models

The term product data, product data management and product lifecycle management are unfamiliar terms in construction industry and BIM and product view should be utilized together to benefit from BIM (Halttula, 2020; Mansoori 2021), as introduced in chapter 2.2. Building information Model is a repository for building information and a database system that is in object-based format. It is different from PDM systems that are file based and carry computer aided design (CAD) and analysis project files. Building model repositories are instead object based, allow queries, transferring, updating and management of individual project objects from heterogeneous set of applications. Building model repository is a central of information that allows each project participant to orient to a single source of information. (Eastman *et al*., 2011; Haron *et al*., 2009; Mansoori & Haapasalo, 2021).

2.4.3 BIM knowledge structures: BIM Framework

Multidimensional BIM Framework is introduced by Succar (2009) as illustrated in Figure 11. It is a research and delivery foundation that allows stakeholders to understand the knowledge structures of BIM. The framework is presented in tri-axial knowledge model that consists of BIM fields (x-axis), BIM stages(y-axis), and BIM lenses (z-axis) as presented in **Figure 11**. BIM Fields is activity identifying domain 'players' and their 'deliverables', BIM Stages is delineating implementation maturity levels and BIM Lenses provides the depth and breadth of enquiry necessary to identify, assess and qualify BIM Fields and BIM Stages. (Succar, 2009). The aspects inside BIM Framework are presented in the following chapters 2.4.4 BIM Fields, 2.4.5 BIM Stages and 2.4.6 BIM lenses.

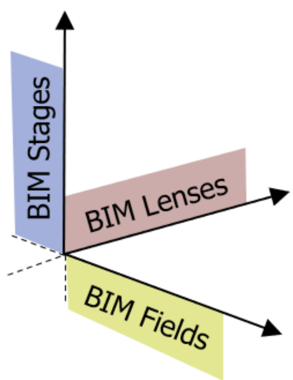

Figure 11. BIM Framework: Fields, Stages and Lenses – tri-axial model modified from Succar (2009)

2.4.4 BIM Fields

In BIM Fields, the focus is on three activity-based fields of technology, processes, and policies as presented in **Figure 12**. Policy field consists of written rules, principles and guides to decision-making, process field is about ordering a specific work, about its inputs and outputs and interactions between design, construction, and operation. Technology field is about the scientific knowledge that is applied for practical purposes. All of these have their own players and deliverables, and the focus is on the interactions and overlaps between these three fields. (Succar, 2009).

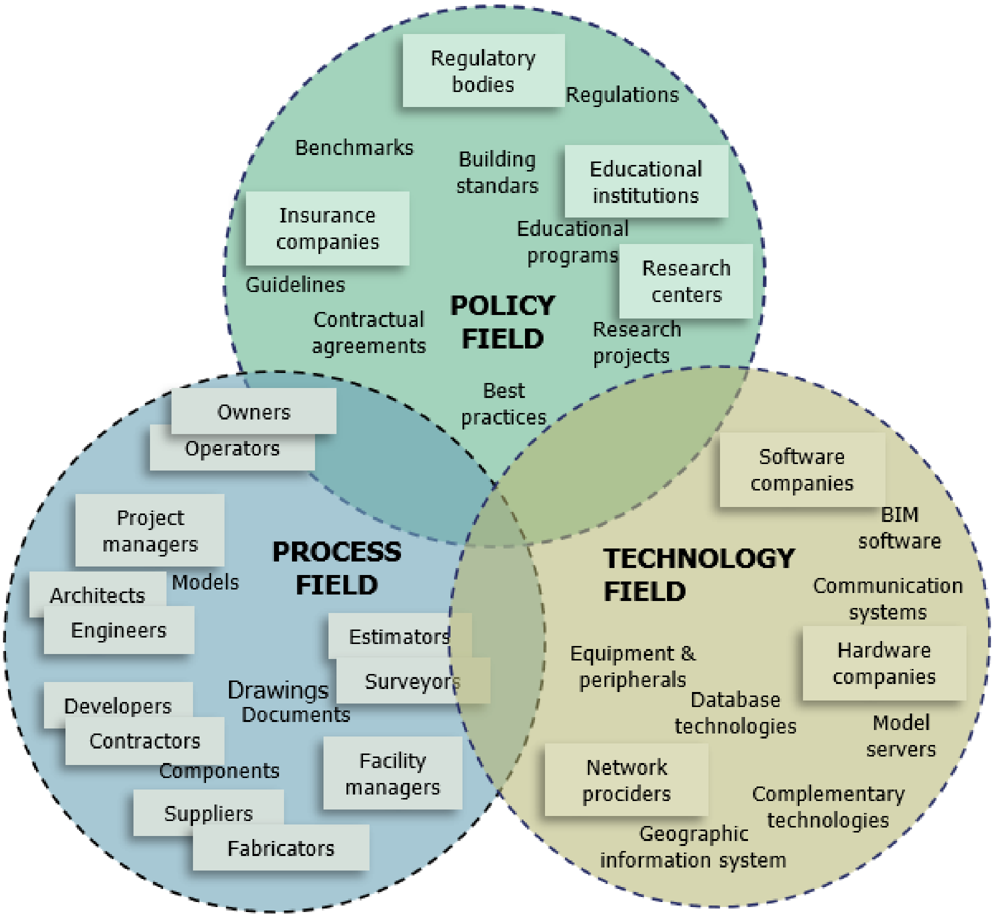

Figure 12. Three BIM activity Fields modified from Succar (2009)

Stakeholders

AECO industry has a great number of stakeholders (Succar 2009, Linderoth 2009) in temporary projects (Linderoth 2009) as presented in **Figure 13**. The client function or organization of a construction project for example can be divided into four roles according to Denicol *et al.* (2021) that have different responsibilities. These roles are owner, sponsor, client, and partner, of which some have more permanent and some temporary role in a construction project. Cliental roles are recognized as "players" in BIM Framework (Succar 2009). According to Denicol *et al*. (2021), owner is the ultimate sponsor who also might be the operator, an example of these are investors. The sponsor is for example public departments and are empowered by the owner. The client is the delivery authority, a single-purpose organization that is empowered by the sponsor to establish contracts and act in the supply chain. Finally, the partner is composed of one or more organizations and are in responsible of augmenting the resources of the client organization. Partners are usually mistakenly understood as the client organization. (Denicol *et al.,* 2021).

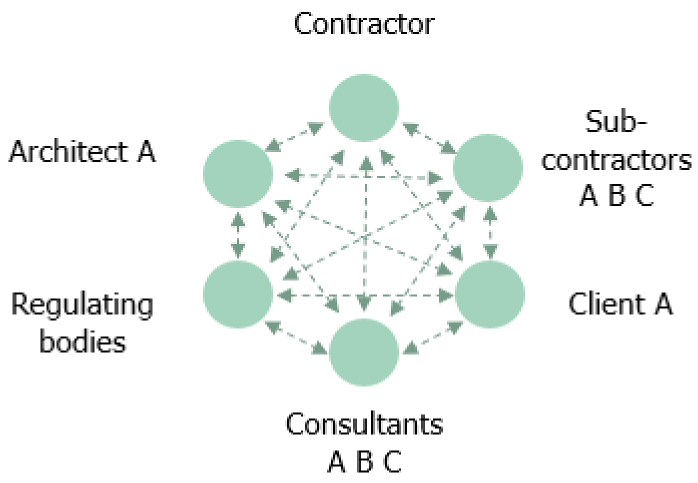

Figure 13. Actors of a BIM based building project organization modified from Linderoth (2009)

Building information models are complex and thus it increases the use-cases for diverse users within heterogeneous building projects (Mansoori & Haapasalo, 2021). BIM users still have problems with lack of experience, lack of client demand, cultural resistance, high software expenses, low demand, insufficient training (Mansoori & Haapasalo, 2021). In BIM framework, Succar (2009) represents a solution to increase the understanding of BIM in integrating product and process modelling and bridge the chasm between academic and industrial understandings. BIM Framework clusters and classifies the industry stakeholders in useful manner. One of the three main aspects of BIM Framework is BIM fields that generate a set of conceptual clusters, in which the active roles can be divided into policy-, process - and technology fields.

Format

Interoperable exchange of BIM data can be done in many technical ways. There are also non-modifiable design data export formats in use, such as PDF and DWF, that do not include modifiable parametric attributes (Succar, 2009). The BIM information can be transferred in proprietary formats, open-proprietary formats, and non-proprietary file formats (Succar, 2009).

An example of proprietary formats are the different design fields' original formats. (Succar, 2009). BIM product models are typically offered in their original, native format, that is dependent on the various software vendors. (Gao *et al.*, 2015). An example of these could be Architect's Revit Architecture and Structural engineer's Revit Structure's (RVT) -file format (Succar, 2009). An example of a non-proprietary file is generally in building industry used Industry Foundation Classes (IFC) file format, that can transfer data from design software to other, example from Archicad (architectural design) to Tekla (structural design) (Succar, 2009).

2.4.5 BIM Maturity stages

In BIM Framework-theory, the BIM Maturity stages include the interaction and challenges between the common stakeholders such as "*architecture, engineering, construction and operations (AECO)*". It focuses on the maturity of the modelling stages from object-based modelling to network-based modelling during the project life cycle taking account how the stakeholders interact and how the model requirements support the interaction. (Succar, 2009).

Lifecycle

It is possible to divide BIM models into categories based on either the lifecycle standpoint by Gielingh (1988), a business process standpoint or a product procurement standpoint. Gielingh's (1988) lifecycle standpoint presents following categories: "*as-required, as-designed, as-planned, as-built, as-used, as-altered and as-demolished*", business process divides models into following 5 categories: "*requirement, design, production, commissioning, and operation model"* and product procurement standpoint divides models into four categories: "*as-designed, as-ordered, as-delivered, and as-owned*" (Cerovsek, 2011). Each of these differ in level of detail and complexity and thus the relationship between each model needs to be defined (Cerovsek, 2011).

BIM Level of Development

BIM Model's maturity stages can be defined according to common BIM requirements (COBIM2012), the first BIM requirements in the world published by the Building Smart Finland forum. COBIM2012 is a collection of BIM requirements that consists of 14 separate parts. It defines different BIM project phases, level of detail needed in modeling, and gives instructions and background detail for modeling. The parts of the requirements are divided based on use-cases and the meaning of the series is to forward collaboration in the usage of BIM.

Another generally used option for defining maturity stages is the American Institute of Architects' level of development, LOD (2008). Level of development, LOD defines the amount and degree of information that needs to be in a BIM Model. It is a framework used to specify the development of BIM model and it helps to communicate and coordinate with the project team. (UnitedBIM, 2020). The American institute of architects introduced 5 leveled concepts of LOD defining amount of detail in BIM model 2008 (*AIA E202 - Building Information Modeling Protocol Exhibit*, 2008) from the basis of Model Progression Specification (MPS) in which core are Level of Detail -specifications. Later in 2013, AIA agreed to allow BIMForum, to utilize its LOD definitions and they developed a LOD Framework, in which there are six development levels (Bedrick *et al.*, 2020; Daga, 2021; van Berlo & Bomhof, 2014) The different LOD levels are presented more in detail in the following chapter.

The first level (LOD 100) is a conceptual level in which model includes spaces and graphical representation with generic shapes and symbols. The elements might only be blocks of approximate sixes. LOD 200 represents the approximate geometry of generic system, object, or assembly with approximate specifications. It presents the geometry perfectly but not any specific details. The third level, LOD 300 is called "precise geometry". In LOD 300 model, there are accurate information of model elements, and it can be used in construction phase. LOD 350, which is only in BIMForum LOD, but not in AIA LOD, is called a "precise geometry with connections". It has the same information that in LOD 300, but also interfaces, supports and connections to other building components. It includes parts that are necessary for coordination between disciplines. LOD 400, "Fabrication" includes so detailed information of model elements that it can be handed over to manufacturer. LOD 500 is also called as "As-built", meaning the geometry and information to support operations and maintenance of the building lifecycle (Daga, 2021).

2.4.6 BIM Lenses

The last axis in BIM Framework is BIM Lenses, that gives the depth and enquiry for the Framework. Lenses and filters generate knowledge views and allow the selective focus on any aspect in AECO industry with the criteria and focus the user needs removing unnecessary or focusing on the important details. (Succar, 2009). BIM provides a powerful tool allowing visual simulations of a project and virtual prototype of a building prior to construction (Takim *et al*., 2013). Finland is considered one of the pioneers of the technology (Takim *et al*., 2013) and in Finnish COBIM (*COBIM*, 2012) regulation series' general part (part 1) there are 28 use cases mentioned in ten categories. These categories include the following:

- Requirements BIM,
- Site BIM,
- Inventory BIM,
- Spatial Group BIM,
- Spatial BIM,
- Building element and systems BIM,
- Preliminary building element BIM,
- Building element BIM in quantity take off phase,
- Building element BIM in construction phase and as-build model

Building Smart International (BSI)'s list of BIM use cases includes over 50 use cases separated to four main categories: design, procure, assemble, operate (*BIM Use Case List*, 2019). Sacks *et al*. (2010) On the other hand introduces 18 BIM key aspects of functionality in design, design and fabrication and pre-construction and construction phases.

2.5 Literature review synthesis

Productization practices in building industry

The literature review shows that a product can either be hardware, software, or a service, and it must be defined in a structured way commercially and technically (Kropsu-Vehkaperä, 2012), and it is something that is sold, delivered, and invoiced (Tolonen, 2016; Mustonen, 2020). Also, productization is needed to gain sellable products in a structured way both commercially and technically (Härkönen *et al.*, 2017; Mustonen, 2020). The literature review reveals that product and productization definitions and practices in building industry have been studied only a little Härkönen *et al.*, 2018; Mansoori & Haapasalo, 2021). The definition of a product is unclear in the industry; product is mainly seen as the physical building itself (hardware) or the building supplies (Härkönen *et al.*, 2018; Maloney, 2002; Mansoori & Haapasalo, 2021). Product portfolios, with commercial and technical items, and neither configurability nor modularity have been discussed together in the context of the building industry (Härkönen *et al.*, 2018).

In the literature, commercial product items are something that are sold, delivered, and invoiced (Tolonen, 2016; Mustonen, 2020). The order-delivery-invoicing practices within building industry are seen to be different from the manufacturing industries' corresponding practices (Grenzfurtner *et al.*, 2020). The OFP in building industry is complex, project based and invoiced by the progress payment method (Maloney, 2002; Ahmadisheykhsarmast *et al.*, 2020; Grenzfurtner *et al.*, 2020), that is based on the work done (Maloney, 2002; Ahmadisheykhsarmast *et al.* 2020). These practices are known to be poor worldwide and known to cause delays and overruns in construction projects (Maloney, 2002; Ahmadisheykhsarmast *et al.*, 2020). Grenzfurtner *et al.*, (2020) state that subsequent design is in a key role in construction industry OFP, but in a secondary role in manufacturing industries OFP. However, it could be questioned whether this statement applies also in ETO and MTO type of processes in manufacturing industries, in which the OFP deliveries are project based.

In conclusion, it can be seen that productization practices are not familiar in the building industry. Progress payment-based order-delivery-invoicing practices in the construction industry do not support the definition of a product, where product master data should remain unaltered thorough the ordering, delivering and invoicing practices of a product. However, even if the currently poor OFP practices moved towards an unaltered product data point of view, it is unclear if that would actually result in less delays and overruns in real life use cases.

Productization of building information models

Building information models themselves, being productized or not, already have broad and multidimensional knowledge structures. BIM framework by Succar (2009) helps to understand these knowledge structures in three dimensions: BIM stages, BIM fields and BIM lenses. This framework alongside with information about BIM model content aspects such as players, LOD, maturity stages, stakeholders, use-cases, lifecycle phases and formats help to structure the information content in BIM models.

According to the literature review, BIM can be referred to as product models and defined to be products in some context (Cerovsek, 2011;(Cerovsek, 2011; Mansoori & Haapasalo, 2021)). Still, productization and product structure of BIM is not discussed much nor applied to practice, even though the potential of it is recognized (Mansoori *et al*., 2021; Härkönen et el., 2018). Building information models are not seen as products legally (Stepanenko, 2019). BIM products are also not defined digitally (Mansoori & Haapasalo, 2021), but it is recognized that model element definitions, such as LOD, have similarities with technical product structure (BOM) (Boton *et al*., 2018). Meanwhile BOM is argued to be the missing link between disconnected processes in construction (Boton *et al*., 2018; Härkönen *et al*. 2018). Applying the productization concept could help to improve the BIM implementation (Mansoori *et al*., 2021).

It can be stated that the study of productization practices is scarce in the building industry (Härkönen *et al*., 2018; Mansoori *et al*., 2021), and there is no indication nor definition of productizing building information models in earlier research. However, productization practices used in other industries have potential for building industry as well. Thus, the buildings can be comparable to any other HW/SW/Services type of the product which are delivered as ETO-MTO or related project delivery model.

3 CURRENT STATE ANALYSIS

3.1 Overview of the methods used in current state analysis

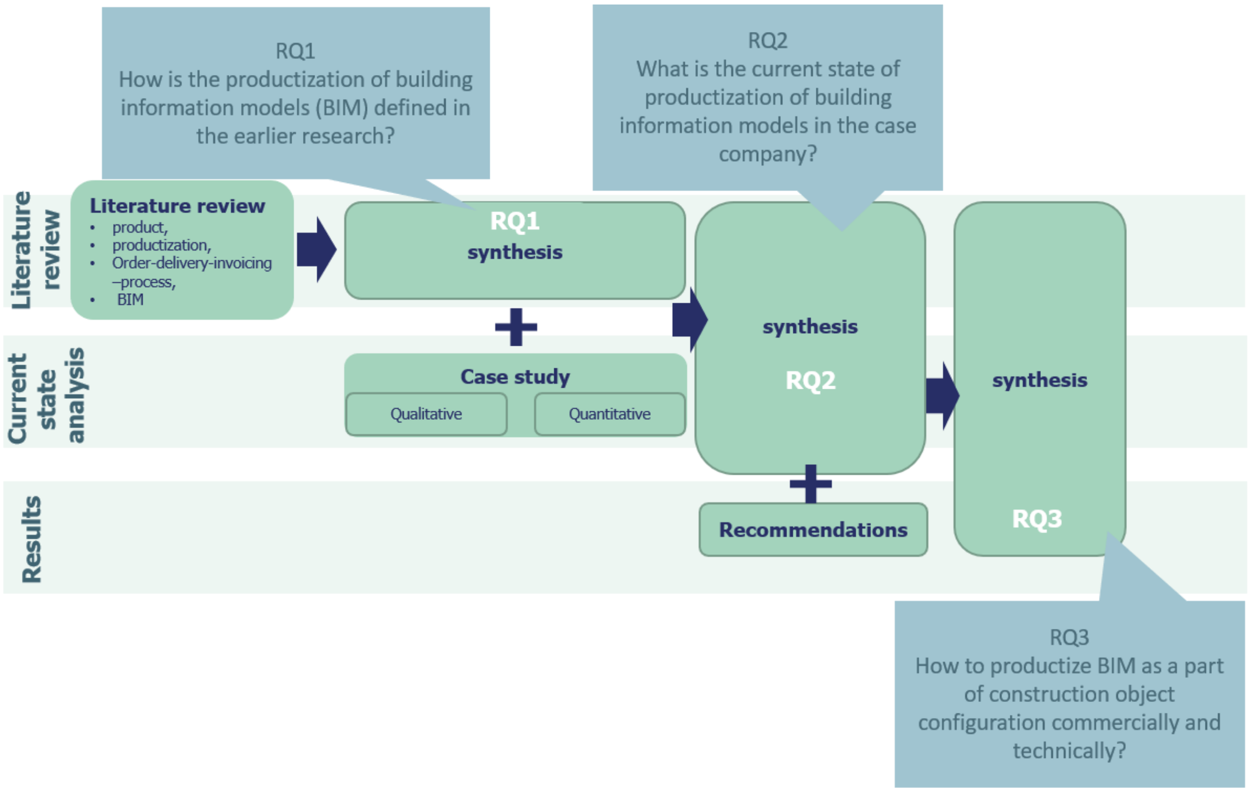

Figure 14. Research process and research questions

The current state analysis of this thesis focuses on research question 2, as shown in **Figure 14.** The current state analysis of this research consists of quantitative and qualitative data, both collected from the selected case company. Quantitative data is collected from PDM system and BIM Key Performance Indicators (KPI's) used in the company, and qualitative study data is collected with eleven semi-structured interviews. Also, basic information and PDM-related information is gathered from Case company documentation such as annual report (Case company, 2021a).

Quantitative data is selected based on the literature findings and it focuses on defining the amount and type of productized products in the case company and amount and type of BIM models in the case company. Productization data is collected from case company's PDM system and BIM data from company's BIM KPI's. (Case company, 2021b)

The interview questionnaire was developed based on literature. The questionnaire focuses on two main topics: order-delivery-invoicing practices of BIM and value of BIM models. Based on the findings in the literature review, eleven interviewees were selected from the case company in equivalent roles in housing department and business premises department shown in **Table 1**. The goal of this division is to emphasize main business areas equally. To perceive a holistic picture of the BIM Model's commercial aspect, all technical BIM roles, all commercial BIM roles, and the commercial managers within the company were interviewed. All the interviews were carried out in Finnish and conducted separately by the same semi-structured form. Each of the interviewees was asked the same questions in the same order.

Table 1. Roles of the interviewees in the case company and categories in the interview

Category in the interview	**Role in the company**
Business manager	Areal Manager, Northern Finland, Premises
Business manager	Areal Manager, Southern Finland, Premises
Business manager	Areal Manager, Southern Finland, Housing
Business manager	Areal Manager, Rest of the Finland, Housing
Sales manager	Sales Manager, Premises
Sales manager	Sales Manager, Housing
Sales manager	Sales & project development manager, Premises
BIM commercial manager	Development Manager, Housing
BIM commercial manager	Manager in schools and lifecycle services, Premises
BIM technical manager	BIM Manager
BIM technical manager	BIM Manager, Premises

The interviewees are categorized into four groups based on their interview role presented in **Figure 15**. The roles are (1) business managers, (2) sales managers, (3) BIM commercial managers and (4) BIM technical managers. These groups are divided to understand the differences in answers of the interviewees closer to pure business roles, sales roles, and BIM roles. This grouping helps to find differences in the answers of people technically aware of the BIM, people commercially aware of BIM, people aware of sales but not necessarily familiar with BIM, and people clearly aware of the business but not necessarily aware of the BIM practices.

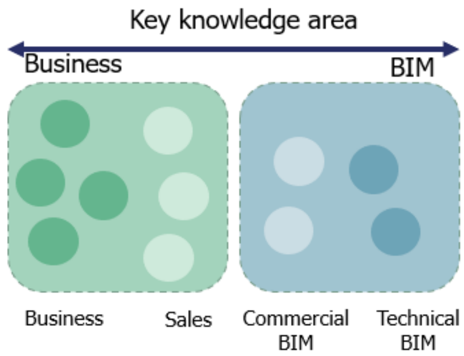

Figure 15. Interviewee categories based on their area of knowledge

The interview questions included eight topics selected based on the literature review. The questions are presented in **Appendix 1**. The topics of the questions were: (1) product, (2) invoicing, (3) phases and stakeholders of BIM, (4) value of BIM, (5) productization, (6) order, (7) delivery and (8) order-delivery-invoicing process. The questions were divided into three sections: (a) building industry, (b) case company and (c) BIM. In the question number 3 there was only sections from a and b sections of the questions due to the nature of the question. Beforehand, questions were targeted to either business or BIM -group to understand and consider the interviewees area of knowledge in their answers shown in **Figure 16**.

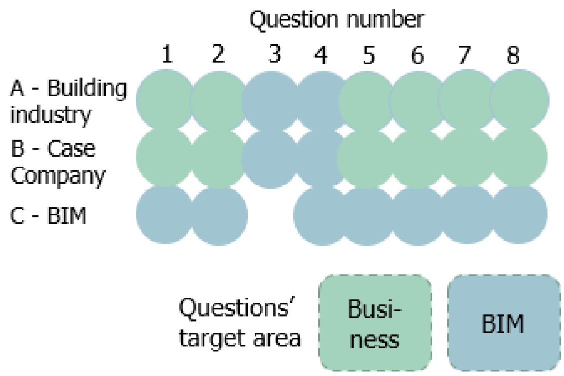

Figure 16. Questions target categories to interviewees based on their knowledge areas

Analysis of the interviews were made based on the role groups under each question. The total outcome of each topic was collected both to groups and to question sections as presented in **Figure 17**.

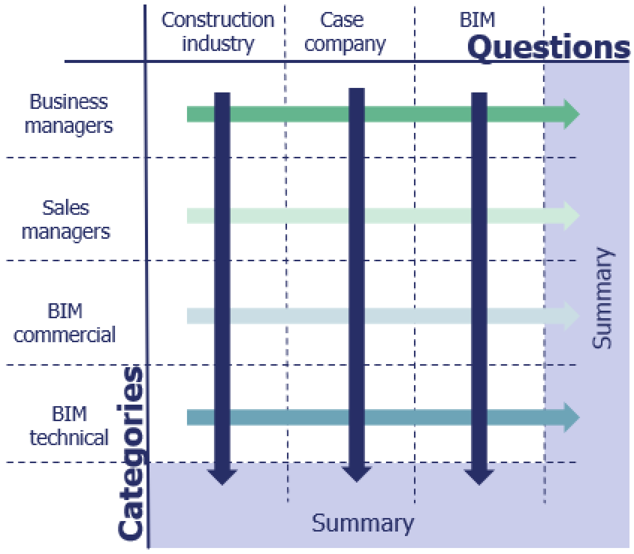

Figure 17. Qualitative analysis method of research questions

3.2 Case Company introduction

The case company of this thesis' current state analysis is a Finnish construction and real estate company that consists of several subsidiary companies including structural engineering and prefabrication. The company's main service areas are business premises and housing. Building information modelling and manufacturing process are stated to be part of company's strategic directions.

The selected case company consists of the following business units: Housing, Business Premises, Components, Sweden, and Structural engineering. Company has ten offices in Finland, and it had 1034 employees altogether 2020 (Case company, 2021a). In 2020 the group's net sales 545 million euros and the operating result –2,9 million euros (Case company, 2021a). Company completed 1459 apartments and 21 business premises in 2020 (Case company, 2021a). The case company owns several parts of construction project's value chain - it is a contractor whose structural engineering is mostly inhouse, architectural design is partly inhouse, and project management, cost calculation and purchasing are handled inhouse.

Strategic key factors for the company are efficient design management, standardization of both operating methods and technical solutions and industrial manufacturing. The company production methods are both engineer-to-order (ETO)/assembly-to-order

(ATO) and make-to-order (MTO). ETO/ATO concern buildings and MTO building components (Case company, 2021a). Case company utilizes product lifecycle management (PLM) using standardized product libraries, modularity, and product data management (PDM) concepts. Currently PLM practices of the firm concern pre-manufacturing products such as elements, modules, and wooden block of flats (Case company, 2021a).

Building information modeling practices are emphasized in case company's webpages (2021). It is said that the digitalization in case company means integrated business processes and building information modeling that is based on master data concept. The organization has two main units operating on construction site projects: housing and premises. The roles regarding BIM in case company are emphasized into three main roles: BIM managers, BIM sponsors and Virtual Design and Construction (VDC) Manager, of which the first two roles are interviewed within this thesis based on their role regarding to BIM. BIM managers take care of the BIM project coordination and BIM technical issues, BIM sponsors deliver the BIM related messages and lead change management among the units and VDC manager leads the strategic work related to BIM. In this study, BIM Managers are referred as "BIM Technical" and BIM Sponsors as "BIM Commercial" due to their roles' natures related to productizing BIM. The case company's BIM roles and communication map within this study is presented in **Figure 18**.

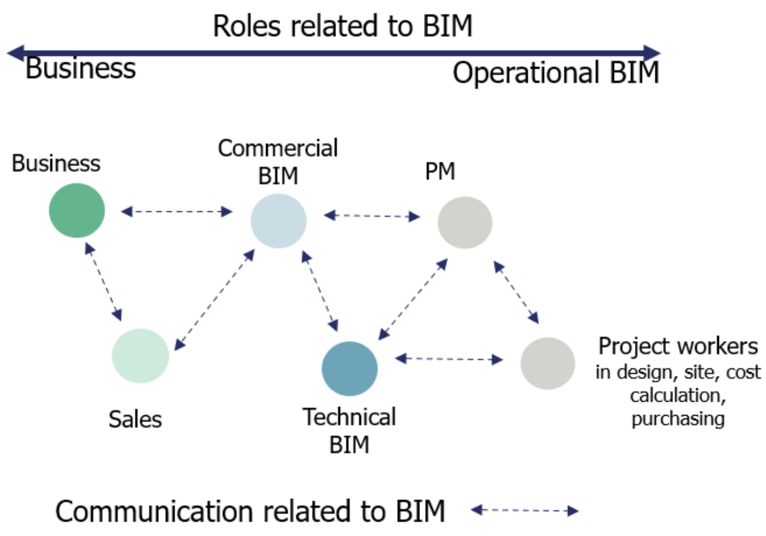

Figure 18. Case Company roles and communication map related to BIM

The building information modeling practices used in case company consist of three main areas which are information managers, information producers, and information end-users presented in **Figure 19**. People working in project management and in company's BIM organization belong to information managers, people working in design belong to information producers and people working in cost calculation, purchasing and construction site belong to information end-users.

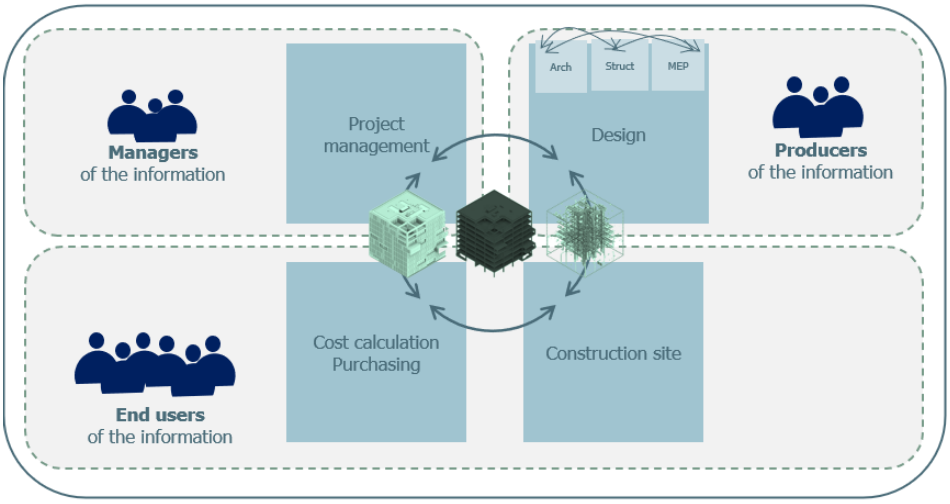

Figure 19. Building information modelling areas in case company modified from case company's operational handbook (2021c)

3.3 Current productization practices in case company

"Building information model that adds value,
could be sold separately or as a part of the building"
-Business Manager

Interviews showed that the definition of a product in the building industry as well in the case company was unanimously considered to be a physical building that may contain subassemblies. Also, service products were recognized as products. Building information models' status as a product divided opinions: the more on the business side the interviewee's position was, the more explicitly BIM models were not considered products. None of the sales managers considered BIM as a product while the technical BIM managers, who work closely related to BIM models, considered them products. The interviewees in the commercial BIM category thought that BIM should be both a commercial and a technical product that is a subassembly of the main building product.

Based on the qualitative case study, the definition of productization is unclear. The interviewees considered productizing in building industry mainly a branding issue, somewhat as a productizing a process, but also as new product design (NPD). There were many “I don’t know” answers related to the productization. Most considered case company’s productization practices being similar than in building industry in general, but more related to standardization. Some recognized that in the case company there are commercial and technical productizing point of views, that differ from the rest of the building industry. All others but technical BIM category had “I don’t know” -answers related to the BIM models’ productization. Business category considered productization of BIM as standardized solutions and building information model software element libraries. It was suggested that productization should be done through the model content requirements.

PLM is being implemented in the case company according to a prioritized road map. Based on the quantitative case study, the case company has tens of pre-fabricated wooden houses, hundreds of modules and sub-assemblies and thousands of items productized in PLM system. According to the press release (Case company, 2021a), the company delivered 1459 apartments and 21 business premises in 2020.

3.4 Order-delivery-invoicing practices in case company

“Order means mainly the same as the contract”
-BIM Commercial Manager

Order

Within both building industry and case company, order was considered as a contract or the consequence of the contract by all but one of the interviewees. It was also seen that an order is a recall of a contract-based issue, the commercial process ends to an order, and a contract seals the order. In the sales category, it was mentioned that order is an “unspoken part of the contract”. In the business category, it was seen that contract includes a lot of unspoken communication that leaves unsolved issues to the production phase. Related to the BIM models as orders, both business related categories had “I don’t know” answers. Ordering building information modeling was mostly seen as part of ordering the project, meaning that the client “orders a BIM project”. At some extent, it was considered that ordering BIM models equals defining the requirements for the BIM.

Delivery

Delivery was considered equal to order, both in building industry and in the case company. Delivery was mostly considered as physical product or part of it that is built according to a contract. Delivery was understood to include constructing work, and it was recognized that in the building industry there are also separate material deliveries that differ from the work performances. It was evident that it was unclear what delivering BIM means. "I don't know" as an answer was general in each category. Some of the interviewees argued that BIM models are delivered as part of other materials and others, mostly people in technical BIM category, stated that building information models were not delivered to the clients.

Invoicing

Interviews revealed that invoicing is based on the progress payment and work done in the building industry in general, as well as in the case company. It was stated that work done, and some other features (risk, time, money, documents, added value and features, materials) are invoiced. Business category and commercial BIM category interviewees emphasized mostly on added value in invoicing. Business and sales category interviewees unanimously mention that invoicing is made based on the progress payment, when again in the BIM categories it was not mentioned at all.

The common understanding was that BIM models are not invoiced. In the sales group there was the most uncertainty related to the invoicing of BIM. According to business and sales groups interviewees invoicing BIM happens at most through the design costs. BIM commercial and BIM technical category interviewees had unanimous understanding of BIM models not being invoiced. The common opinion was that currently BIM is not invoiced, but especially business category saw the potential of invoicing of BIM based on their added value. BIM commercial category interviewees found it strange that even though the construction company pays consultants for the building information modeling work, companies do not invoice it from the client. Thus, BIM commercial category alongside with BIM technical category and business category interviewees thought that BIM models could be sold on additional price.

"We don't properly define anything; we just work"

-BIM commercial Manager

OFP

Order-delivery-invoicing process was unanimously seen as sequential operation both in the whole building industry and in the case company. It was stated that "*we don't properly define anything, we just work*". In the BIM technical group it was thought that working may start even before the order. The closer to business category the interviewees were, the clearer opposite opinions were present: either BIM was seen part of the order-delivery-process like everything else, or it was seen fully separate part of the order-delivery-invoicing process. Based on the amount of "I don't know" answers, the sales category group was completely unaware of the current practices. At the same time commercial BIM category group's unanimous statement was that there are no current practices related to BIM models' order-delivery-invoicing practices. Members of the BIM technical category group thought that adding BIM to order-delivery-invoicing process could be the future goal and stated that BIM models could be created and invoiced as additional work like many other things in construction industry.

3.5 Building Information Models: stakeholders, phases, and value

"BIM could add value to construction, facility management and renovation"

-Business Manager

BIM stakeholders were mostly recognized from the inside of the organization and emphasized in the design phase. Especially in business group it was recognized that utilizing BIM has unrevealed potential in the later lifecycle-phases, like in facility management (FM) and renovation. Most interviewees of the sales category had "I don't know" as an answer. The closer to BIM technical category the interviewees' role was, the less unused potential was recognized in BIM. BIM model was considered more of a tool for managing the project and used collectively. It was also seen to have no clear owner. The BIM stakeholders and phases in current practices and potential practices are listed in the **Table 2**.

Table 2. Current and potential phases and stakeholders recognized in the interviews

Current and *potential* phases recognized:	**Current and *potential* stakeholders recognized:**
– Commercial phase – Predesign – Design – Prefabrication – Production /construction – Marketing – *Renovation* – *Facility management (potential)* – *Maintenance* – *Warranty*	– Inner stakeholders during the project – Authorities – *Clients, investors* – *User/maintenance of the building* – *Investors not interested* – Production

The values of BIM in the building industry were seen to be quality check of the design fields, optimizing, containing data and the data content itself. Though, technical BIM category group recognized that the amount of the data and validity of data are core issues, and they correlate with added value of BIM models. The value of the BIM was mostly seen similarly, but in the sales category group some potential new business cases were recognized for BIM. Business group was unanimous that price of BIM should be defined based on the value, not cost. Sales and commercial BIM category groups stated that currently BIM's assumed price is more defined based on cost, even though it should be defined based on value. Commercial BIM category interviewees insisted that case company does not believe in building information modeling enough and its value is not seen or understood.

The answers of the interviewees regarding to BIM stakeholders and phases indicate, that the closer the interviewed people work with BIM in daily work, the more aware they are that the utilization of the building information models in commercial aspect is missing. At the same time the business managers, who are furthest from BIM in daily work, were the most eager to see the potential commercial value of BIM.

The usage of BIM in the case company was evaluated through quantitative data, presented in **Figure 20**. The data was collected from the case company PDM system and BIM Key

Performance Indicators (KPI's). The BIM usage in this case consists of seven equal main areas that are measured from each BIM-based project. The categories being measured are (1) BIM coordination, (2) Combined model, (3) architectural model, (4) structural model, (5) HVAC-model, (6) electrical model and (7) GEO-model. If all these areas are in use in each BIM project of the case company, the usage is 100%. The usage in the case company BIM projects is 83%. The data shows that in all BIM-projects at least three out of four contained architectural, structural, HVAC and electrical models, those being the most common design fields within BIM.

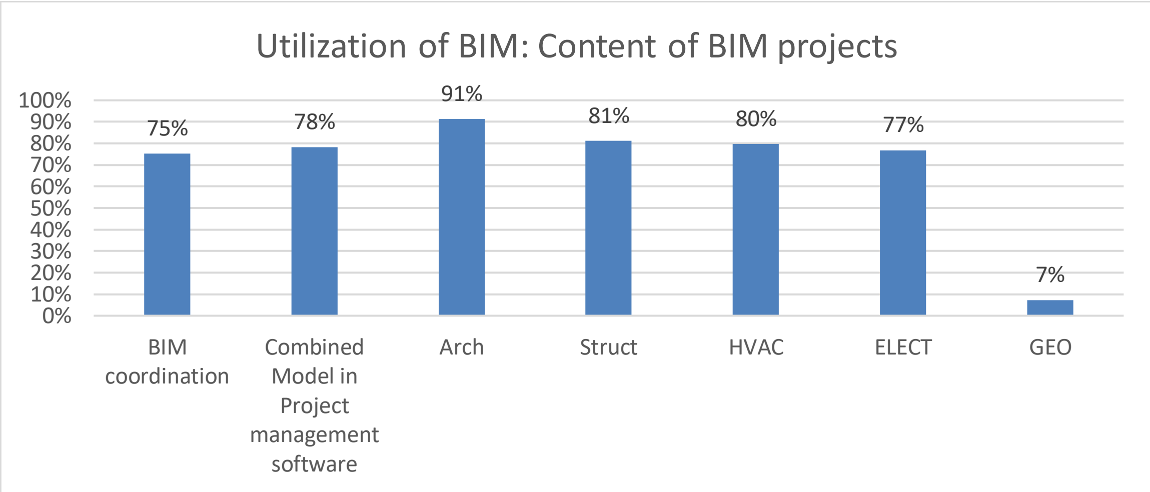

Figure 20. Utilization of BIM in Case Company's BIM projects

3.6 Current state analysis synthesis

The key statements from the literature review and current state analysis are collected to **Table 3 & Table 4.** These statements outline the arguments behind the recommendations of this work. "X" marked in the empirical study -column and references marked in the literature review column indicate that the statement in the same row is supported by that particular section of the study. From Tables 3 & 4 it can be discovered that most of the key statements are supported both by literature review and empirical study of the thesis

Table 3. Statements related to product, productization and order-delivery-invoicing definitions and current practices in building industry

No	Statement **product, productization and order-delivery-invoicing: definitions and current practices in building industry**	Literature review	Empirical study
1	Product can be hardware, software or service and it must be defined in structured way commercially and technically	Kropsu-Vehkaperä, 2012; Tolonen, 2016; Mustonen, 2020	
2	Productization is needed to productize sellable products in a structured way	Härkönen *et al*., 2017; Mustonen, 2020	
3	Products are something that are sold, delivered, and invoiced	Tolonen, 2016; Mustonen, 2020	
4	Product definition is unclear in building industry	Mansoori *et al*., 2021; Härkönen *et al*., 2018;	x
5	Product is mainly understood as physical product in building industry	Mansoori *et al*., 2021; Härkönen, 2018; Maloney, 2002	x
6	Order-delivery-invoicing practices are not clear in building industry and differ from the corresponding practices in manufacturing industry	Grenzfurtner *et al*., 2020; Maloney, 2002; Ahmadisheykhsarmast *et al*., 2020; Grenzfurtner *et al*., 2020	x
7	Order-fulfillment is project based and invoiced by progress payment methods in building industry	Maloney, 2002; Ahmadisheykhsarmast *et al*., 2020; Grenzfurtner *et al*., 2020	x
8	There are no clear orders in building industry	Grenzfurtner *et al*., 2020	x
9	Contracts are considered as orders in building industry		x

Table 4. Statements related to current state of productizing BIM

No	Statement **current state of productizing BIM**	**Literature review**	**Empirical study**
10	BIM models don't fit into the definition of a product or productization	Mansoori *et al.*, 2021; Mansoori & Haapasalo, 2021; Härkönen *et al.*, 2018	x
11	BIM is recognized as technical product at some extent	Boton *et al.*, 2018	x
12	There aren't any commercial practices found related to BIM models	x	x
13	BIM is not seen as product legally	Stepanenko, 2019	
14	BIM is not considered part of the order-delivery-invoicing process		x
15	There are no current invoicing practices of BIM but it is delivered as part of the building deliveries		x
16	BIM models are seen as assemblies that are part of the physical building products or part of the design process		x
17	BIM has an individual value		x
18	BIM should be evaluated based on value		x
19	BIM value consists of the quantity and quality of data in it		x
20	BIM offers value in the later phases of project lifecycle		x

3.6.1 Current state of productization practices

Current state analysis of the case company and literature review both indicate that product definition in the building industry is unclear (Mansoori *et al.*, 2021; Härkönen *et al.*, 2018), product is mainly understood as the physical building itself, but based on the literature review products may also be building supplies (Mansoori *et al.*, 2021; Härkönen, 2018; Maloney, 2002). General definition of a product based on literature review says that product may be either hardware, software, or service (Kropsu-Vehkaperä 2012), and it has commercial and technical structure (Tolonen 2016, Mustonen 2020).

Both the literature review and case study indicate that productization is unfamiliar term in general and especially in the building industry (Mansoori *et al.*, 2021; Härkönen, 2018; Maloney, 2002). In the building industry, it is likely to be seen as a branding issue based on the interviews, while based on the literature review productization is needed to productize sellable products in a structured way both commercially and technically

(Härkönen *et al*., 2017; Mustonen, 2020). In conclusion of the empirical study and the literature review, building industry seems to lack the understanding of products other than hardware and lacks the understanding of productizing. Essentially, there is no understanding for the need of commercial and technical product portfolios.

Literature review and empirical study indicate that order-delivery-invoicing practices are not clear in the building industry and differ hugely on the manufacturing industry's corresponding practices (Grenzfurtner *et al*., 2020; Maloney, 2002; Ahmadisheykhsarmast *et al*., 2020; Grenzfurtner *et al*., 2020). It was discovered in the interviews that in the building industry contracts are considered as orders, order-fulfillment is project based and invoiced by progress payment methods. These findings support the findings in literature review. Based on the literature review and supported by empirical study, there are no clear orders in the building industry (Grenzfurtner *et al*., 2020). Delivery content changes throughout the project and thus progress payment content cannot be precisely agreed in advance, but it needs to be connected to time and project progress instead of product deliveries. All in all, the preconditions for productizing in the building industry are currently unclear and there is not much current practices nor theory of it available.

3.6.2 Current state of productizing building information models

Building information models are a recognized term, but at the same time it doesn't fit into definitions of commercial and technical products by Tolonen (2016) and Mustonen (2020). Also, literature shows that BIM models are not products legally (Stepanenko, 2019). Literature review indicates that BIM resembles product and product structure (BOM) definitions (Boton *et al*., 2018) and literature review and interviews both indicate that it is recognized as technical product to some extent, but currently there are no defined commercial practices related to building information models. The case study shows that it is not a recognized part of the order-delivery-invoicing processes. Based on the current state analysis there are no current invoicing practices for BIM models, but still they are delivered to some extent as a part of building deliveries.

Based on the empirical study, building information models are mostly seen as assemblies as parts of the physical building products or parts of the design process. Still, interviews indicate unanimously that BIM has value of its own and the value consists of the usability of BIM. This means the quantity and quality of data in BIM. Also interviews indicate that BIM is seen to offer remarkable value to the users especially in the later phases of the project lice cycle.

The conclusion based on the literature review and empirical study is that BIM models are recognized to be an asset to an organization, despite them not being treated as an asset. Potential in productizing building information models commercially and technically is evident. However, the definitions regarding to productization in building industry are vague and few. One of the reasons being poor order-delivery-invoicing practices of the industry that complicate the understanding of commercial product structure. The industry's general difficulties in productization also apply to productization of building information models. There are not many preconditions applied in the literature in building industry to productization of BIM. The current state of productizing BIM models in case company is missing hence the earlier statements applying to the whole building industry. In conclusion, the case company is a good example of the general situation within the state of productization of BIM models in building industry. Even though the practices on productizing BIM models is not evident as such, the preconditions to productize them can be collected from the general productization theories (Tolonen, 2016, Mustonen, 2020) using the help of BIM Framework theory (Succar, 2009) and other BIM related theories and requirements such as LOD and COBIM2012.

4 PRODUCTIZING BUILDING INFORMATION MODELS

" Building information models is worth nothing if there is not defined price for it"

-Sales Manager

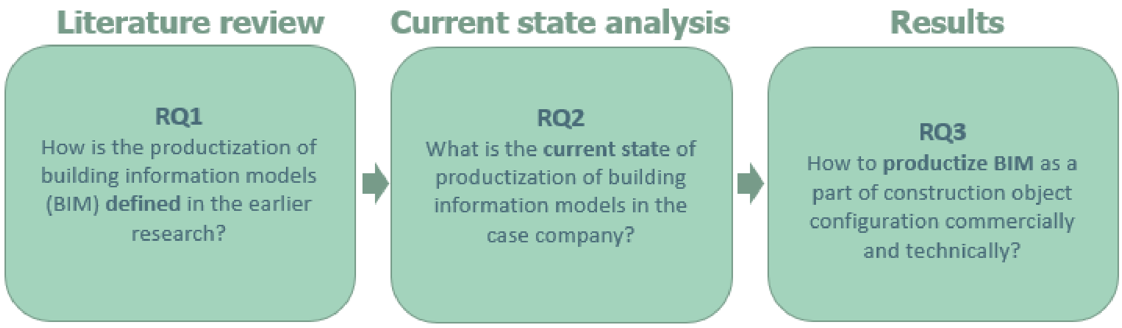

Figure 21. Research process

The results of this thesis are formed through focusing to literature review followed by a current state analysis of the selected topics as presented in **Figure 21**. The results of this thesis can be divided into three key findings presented in the **Figure 22**: (1) Product configuration, (2) Product categories and (3) Product structure

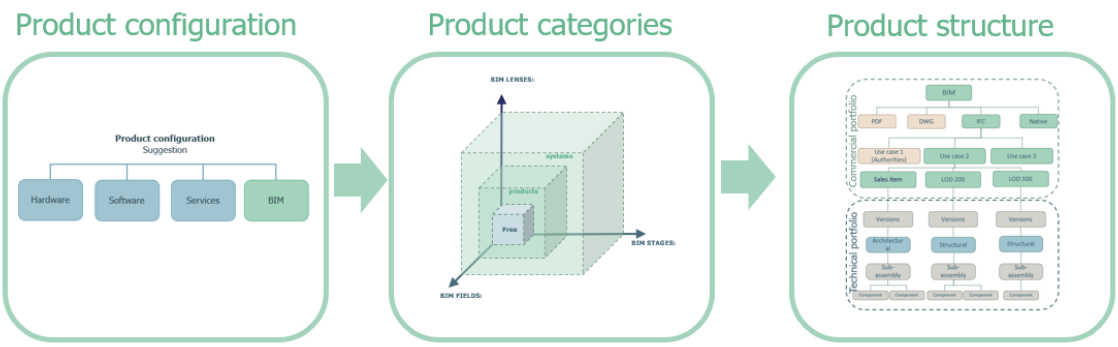

Figure 22. Key results of the thesis

4.1 Product configuration of building information models – *data as an asset*

Literature review and empirical study indicate that currently building information models are not considered as products. However, interviews indicate that building information models have their individual value that consists of the integrity and amount of the data, and they should be evaluated value-based. This indicates that BIM based data should be seen as an asset. As building information models have their own unique value apart from the actual building that is built based on these models, they should not be productized as hardware product's assembly, but as their own product type. Since building information models' value consists of the data originated principles, it is recommended to form a new product category in product configuration. As shown in **Figure 23**, the current understanding of building product configuration is hardware, software and services, hardware being mostly physical buildings. As a result of this thesis, it is suggested that alongside with the three existing product categories, a fourth product category would be established: BIM models. The suggested new product configuration in building industry is presented **in Figure 23**. Also, the corresponding of the case company are presented in the figure to indicate a case example. In the case company, there were no software products in the configuration.

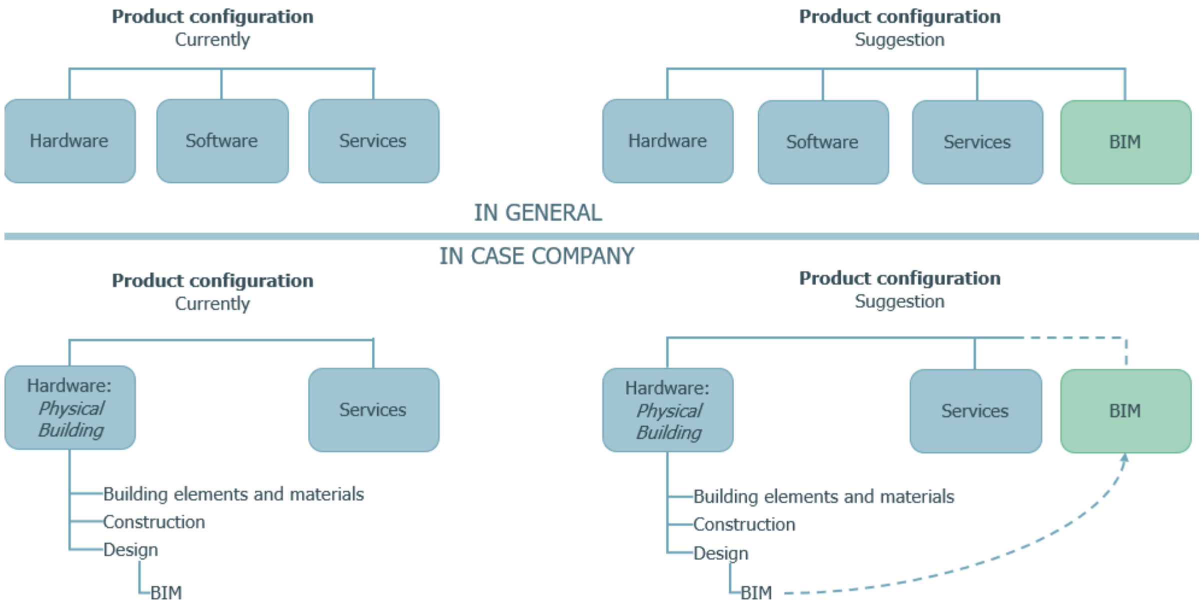

Figure 23. Product configuration suggestion

4.2 **"BIM Framework" in productization** of building information models - *acknowledging the value of data*

4.2.1 Building information model product categories

Various stakeholders use BIM models during different phases of the project lifecycle. On top of that, BIM models have numerous use-cases depending on the purpose and content of the model. In addition, BIM models have unused potential in the later phases of the lifecycle, that is currently not even utilized.

In order to have various stakeholders and use-cases, BIM models knowledge structures need to be broad and multidimensional. Being examined from certain point of view, BIM models' knowledge structures are recognized to have similarities with BOM. In addition, BOM and product structure are seen to be the missing link in utilizing processes efficiently in construction industry. Bilal Succar (2009) introduces BIM Framework to help understand the complex knowledge structures in BIM models. It is suggested to use this framework in productizing BIM models in a structured way to technical and commercial items.

When considering BIM models' data as a valuable asset to an organization, it is crucial to understand the differences of the value in different BIM models. BIM models may be anything users want; this is at the same time the brilliance and difficulty of their knowledge structures. Thus, it is important to understand differences of BIM models based on their value, in which having categories based on the value of BIM models helps. Some BIM models are needed to open access communication by authorities when again some can include essential strategic information and should not be sold for almost any price. As a result, it is recommended to categorize BIM models into three main categories based on their intended purpose of use: (1) Open BIM models, (2) BIM model products and (3) BIM model systems, that are presented in **Figure 24**. Categorizing accordingly helps to keep the focus on productizing commercial items in right direction. Categorizing helps to recognize, which BIM models could be utilized as commercial BIM model products and non-commercial BIM models.

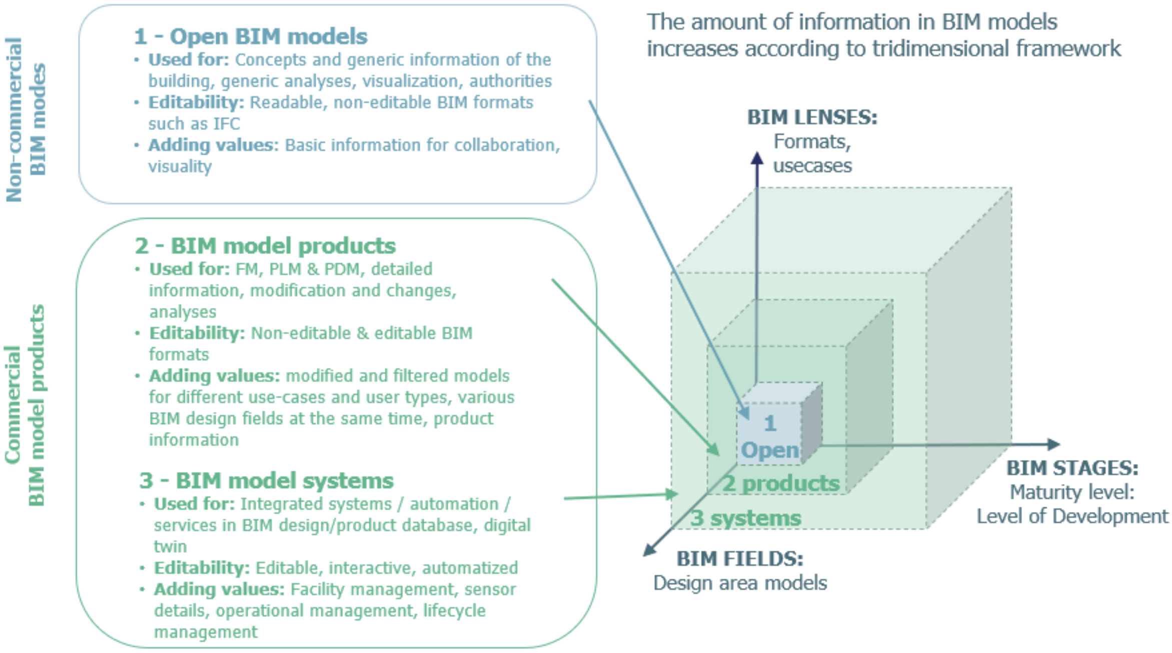

Figure 24. BIM product categories based on their value

Open BIM models can be used for conceptual and generic information transfer, and they may include information that is used for example by authorities. The potential use-cases are generic analyses and visualization. This category is read only, non-editable format such as IFC. They add value in the means of collaboration with and between authorities, design group and communities. These models are suggested to be free due to their obligatory delivery role in a building process.

The commercial product categories are suggested to be divided into two main categories being **BIM model products** and **BIM model systems**. The first of these two is used for facility management, PLM & PDM, detailed information and in modification, changes ana analyses. This category may either be non-editable or editable, depending on the use-case. They add value in modifiability and product information, use-cases being filtered in as many variations as wanted. Models in this category may be in editable native formats and might include various design fields' models

The last category is the one that has most unutilized potential. They are commercial BIM model products called **BIM model systems**. Based on the current knowledge, these BIM models can be emphasized to the later phases of a building's lifecycle. The models are enriched, and they include user interface, attached systems and services around their design and product databases. They may be interactive, automatized and thus editable.

The models in this category may include such BIM models as digital twins. The adding value in this category may be their functionalities in facility and operations management, sensor data and their controllability over the actual physical building. This is the most advanced category in the means of data content, interaction, and functionality.

4.2.2 Commercial building information model products

Productization of a technology is focusing on gaining success by converting technologies into products. The logic helps to clarify and tangibilise the offering for sales, delivery, and invoicing by making configurable elements to commercial portfolio and modularizing them in technical portfolio. Productization defines company's products in product portfolio, and it is an act of modifying something into commercial products. BIM Framework helps to approach the topic of building information models step by step by opening the knowledge structures of BIM models in organized manner to forward the productization practices of BIM models.

BIM product categories, their interfaces, and details, are defined with the BIM framework. Succar's (2009) original BIM Framework dimensions are BIM Fields, BIM Lenses and BIM Stages. These three dimensions are suggested to be used in the basis for adding proper content types to BIM model product categories and later BIM model product structures. They guide in collecting the content options from multiple variations of knowledge structures of BIM models.

BIM Fields guides choosing the deliverables and players (process, policy and technology) around the building information modeling. For example, different design area models or model formats can be used in this axis' knowledge content. *BIM Maturity* stages are delineating implementation maturity levels. For example, level of development (LOD) or lifecycle stages can be used in this axis' knowledge content. *BIM Lenses* provide the depth and breadth of enquiries in order to assess, identify and qualify BIM Fields and BIM Stages. For example, use-cases based on the organizations stakeholders' goals and needs can be used in this axis' knowledge content. **Figure 25** and **Figure 26** present potential examples, how BIM Framework can be utilized in productizing, both in categorizing and defining BIM product structures

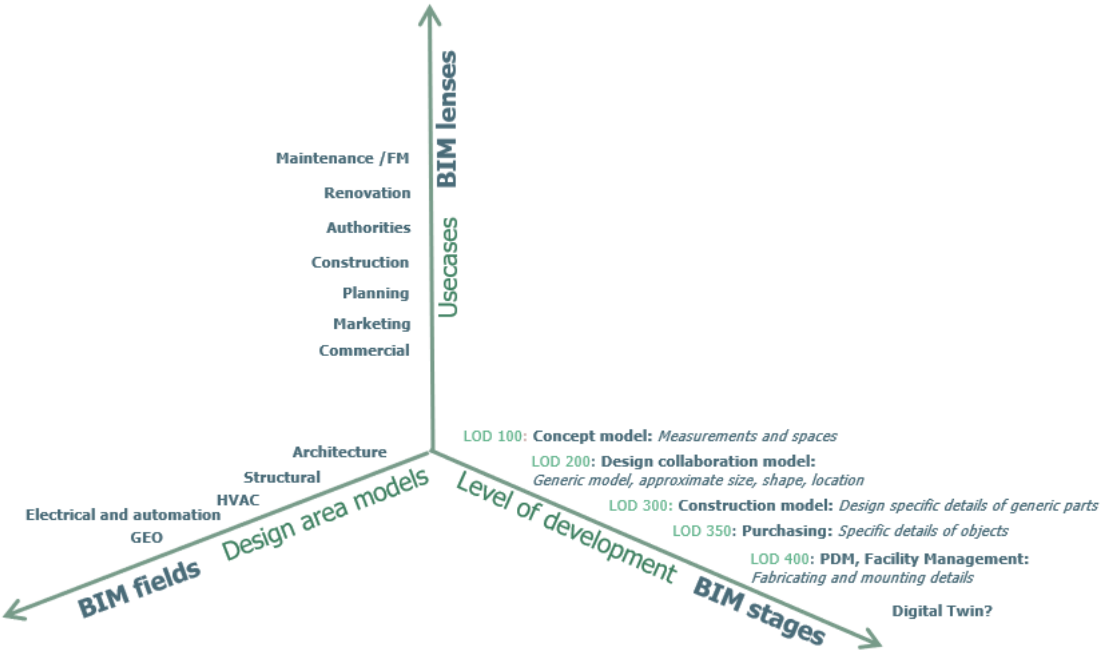

Figure 25. BIM Framework (Succar, 2009) used to define commercial and technical productization interfaces, example 1

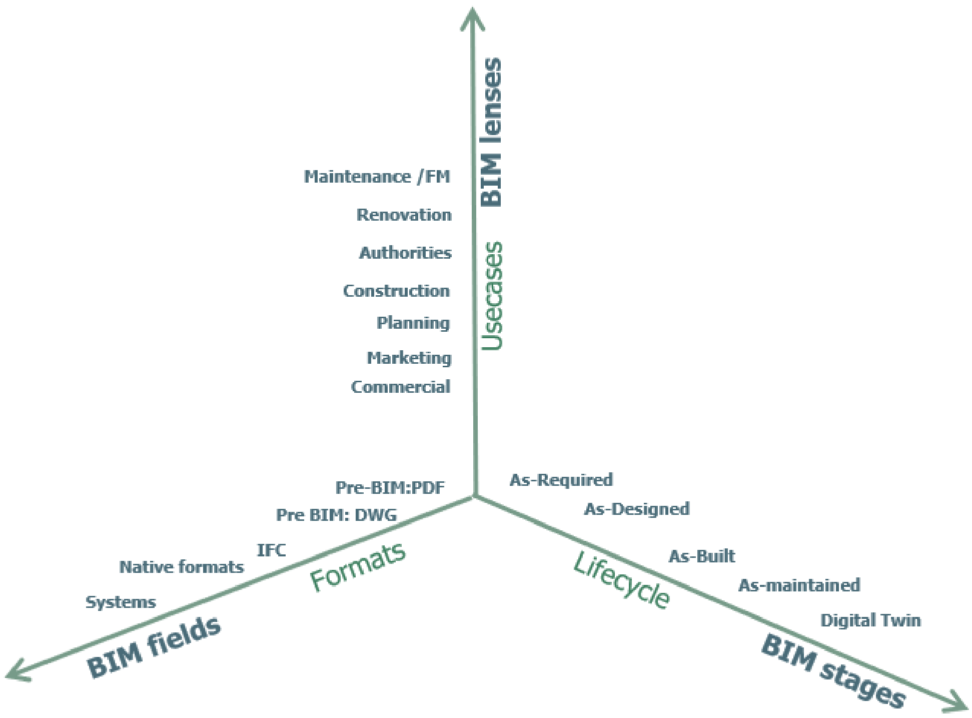

Figure 26. BIM Framework (Succar, 2009) used to define commercial and technical productization interfaces, example 2

4.3 **Product structure** of building information models – *backbone to understanding*

Clear product structure and the levels of it should be defined to unify and realize products and help in data consistency. Product structure should include commercial levels such as solution, product families, product configurations and sales items that are visible to customer. The technical structure of the product should include version items, assemblies, sub-assemblies, and components visible to company. Product structure for BIM model products can be formed after forming proper set of BIM stages, BIM lenses and BIM fields. Each organization has their own strategic goals, business areas, clients and stakeholders. Thus, it is essential that the knowledge content of the BIM Framework axes are chosen based on the organizations' point of view. This will help structure product content in most efficient and useful way. In order to serve customer usability, the product structure in commercial side should be kept on the customer configurability. This means, that the emphasis on BIM model product structure should be kept on the BIM lenses axis, having knowledge content of users and use-cases. Some BIM model product structure examples are presented in **Figure 28** and **Figure 29** which **Figure 27** helps to clarify. The focus of BIM models product structure examples is kept in the commercial side to make understandable product families, configurable products and possible sales items, still considering the technical constraints of BIM models at the same time.

In the first example, in **Figure 28,** BIM fields are selected to include formats, that defines product families in the example. Use-cases are selected for the BIM lenses-axis in this example. Use-cases define the configurable product types. The Bim stages-axis is based on LOD and defines the sales items in product structure example. This particular example could be suitable product configuration targeting to stakeholders that have some technical understanding over BIM, since the product families are made based on the BIM model delivery format. This example is helpful for example in the cases where it is seen important to emphasize on the editability to the customer over the design area models. In the technical portfolio, the assemblies are selected per design fields automatically based on the selected use case.

In the second example in **Figure 29** BIM lenses include use-cases, that defines the product families. BIM fields include formats, that defines configurable products. BIM fields include the design area models, such as structural design model, and are used for defining sales items. This product structure example serves for example customers, that are not quite aware of the technical content and BIM content structure.Customers in this example can select directly products based on their intended use-case, then select the suitable level of editability and finally configurate the design area models which they want to include. In technical portfolio, the lifecycle phases and level of detail change according to customers selections automatically without customer needing to know about them more specifically.

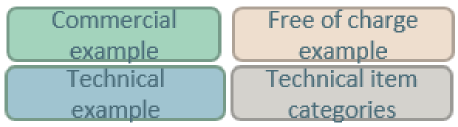

Figure 27. Color legend in BIM model product structure examples

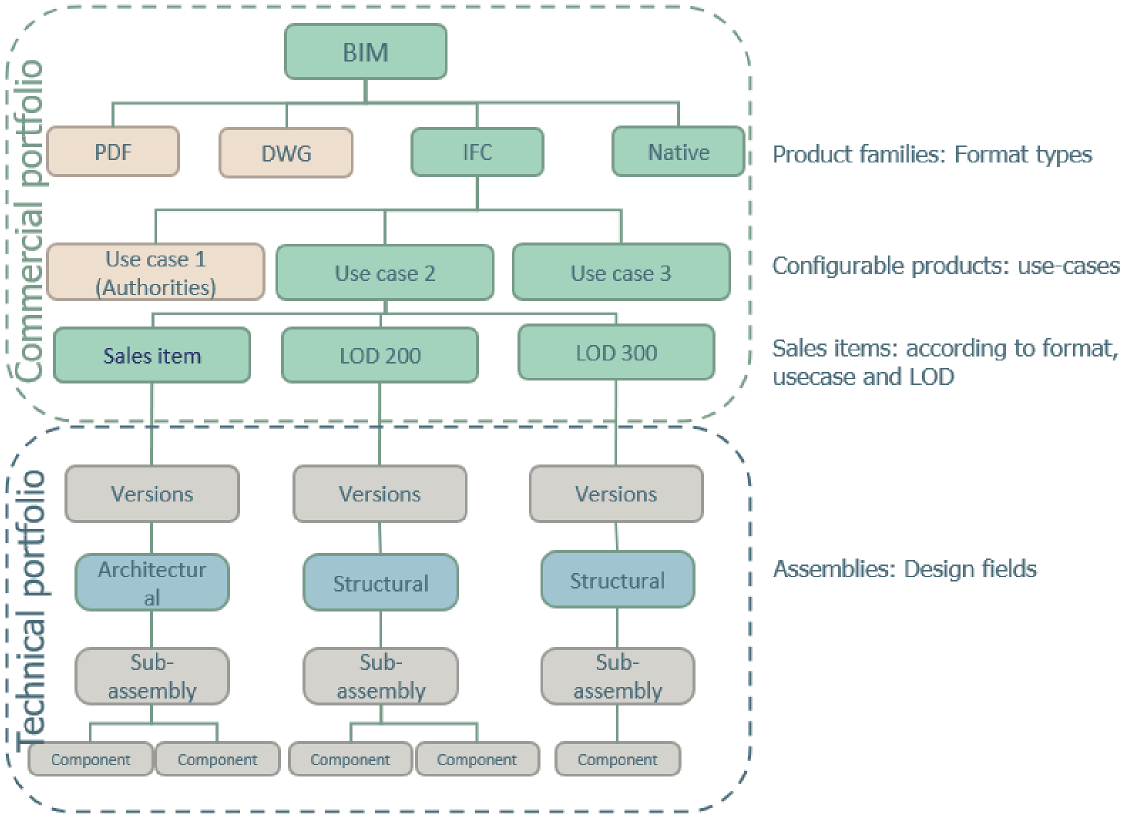

Figure 28. BIM product structure example 1

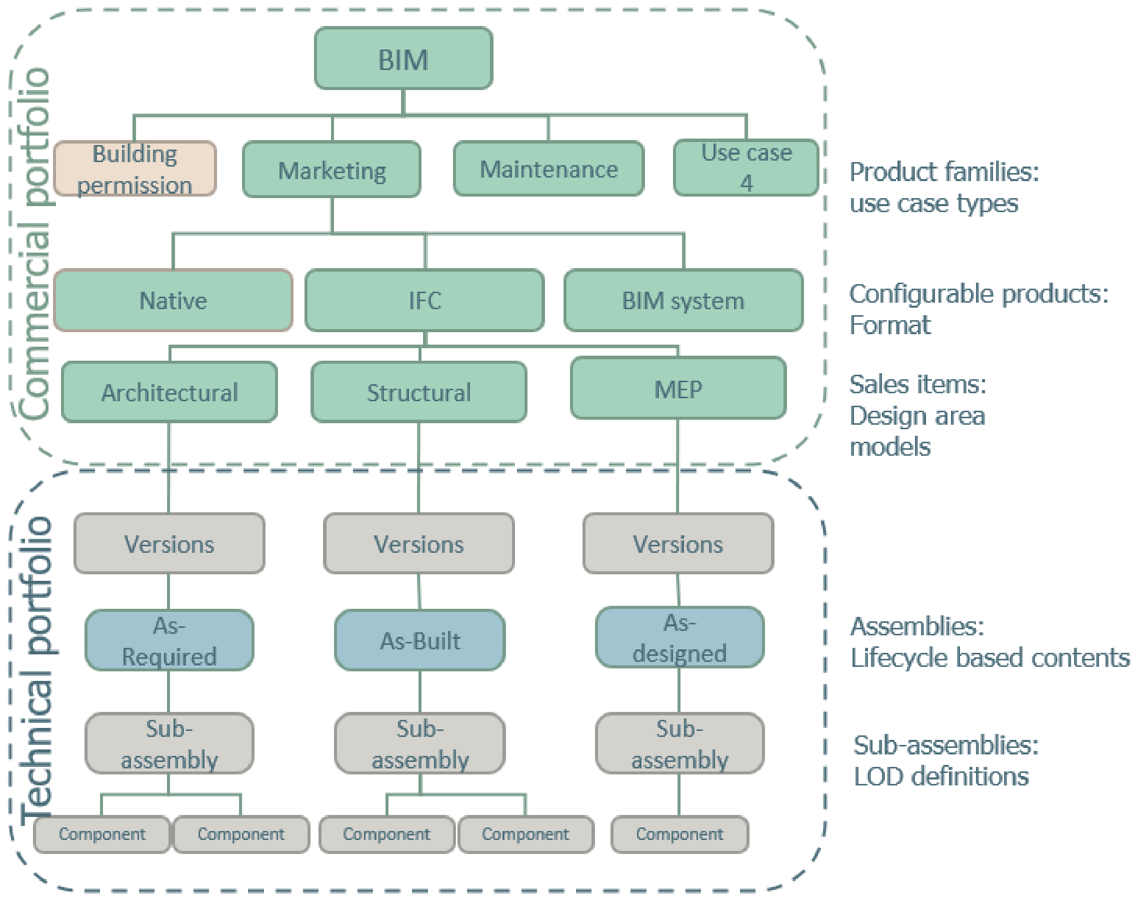

Figure 29. BIM product structure, example 2

5 CONCLUSIONS AND DISCUSSION

5.1 Main contribution

Building information models store huge amount of data continuously in many phases of building lifecycle. They are massive data containers with their complex knowledge structures. Still, the value of their data as an asset is not understood or taken into use in building industry. Seeing BIM models' value as an asset and maintaining a structured PLM in organization leads to need of productization of BIM models, just like tangible products.

Building information modeling is a known term within the building industry when again product lifecycle management (PLM) is quite unconventional. PLM including productization practices are not much discovered in the academia nor used within the building industry. Product structure, a part of PLM and its productization practices, is claimed to be the missing link in releasing the unleashed potential in building information models to forward the functionality of processes and productivity in building industry. This thesis studied the definition of productizing building information models in academia and the current state of it based on the findings in case company. Also, the study focused on how to productize building information models to commercial and technical items as part of building object configuration.

The goal of this study was to focus on helping define productization practices of building information models for organizations producing them. The initial reason for starting this research was to figure out the current productization practices of BIM models and recommend new potential productization practices for BIM models. The topic was seen essential for organization in order not to not lose the commercial benefit of the current design tool and valuable building data containers, BIM models. It was seen important to research further the potential of BIM products as commercial products and their data as an asset for an organization.

As a result of this study, it was found out that BIM models were seen to have their unique and individual value and having potential if being productized in a structured way. BIM models' potential value was found out to grow towards the end of the lifecycle of the building, and value was discovered to correlate on the amount and quality of the data content of BIM models. As an answer to **RQ1** "*How is the productization of building* *information models defined in current literature?"* it was found out that products should be ordered, delivered, and invoiced, but BIM models are not handled as products in order-fulfillment process and there is no evidence of productizing BIM models in current literature. As an answer to **RQ2** "*What is the current state of productizing building information models in case company?"* it was found out that most of the findings in the literature are also supported by the empirical study. The case company had no current practices of productizing BIM models. Still, it was found out that the case company had some ongoing productization practices unlike generally in the industry there is. The key findings in general were that building industry has weak order-fulfilment practices not to mention poor progress payment practices, that are seen to be one of the key causes for delays and overruns in construction projects. At the same time having significant deficiencies in OFP, productization practices are quite new to the industry. The utilization and focusing on productization should be considered as one solution and seen as motivation to decrease the deficiencies in delays and overruns in construction projects. The key findings related to RQ1 and RQ2 are summarized in table 3 and table 4 (chapter 3.6).

As an answer to **RQ3**, "*How to productize BIM models as part of construction object configuration commercially and technically?"* it is recommended that building industry's object configuration would establish a new product category: BIM model product. It also recommended to categorize BIM models into three main categories based on their purpose of use: open BIM models, BIM model products and BIM model systems, the latter of two being commercial BIM model products. Also, as a result, it is recommended to use tridimensional BIM Framework (Succar, 2009) including BIM fields, BIM maturity stages and BIM lenses in defining the product structure for BIM models especially in the commercial side of the product portfolio. The framework is recommended to be used to ease define the multidimensional and broad knowledge structure into commercial configurations and onwards into technical items. All in all, the results focused on helping organizations productize building information models as part of their PLM and product configuration.

All in all, as a result of this study, it is recommended to establish new product configuration to product offering, use main categories in recognizing BIM products value, utilize BIM Framework and finally define BIM model product structure of building information models as it was summarized in the results chapter in **Figure 22**.

5.2 Managerial implications

Huge amount of building related data is contained in building information models. Still, the value of this data as an asset to the organization is not fully understood and has great unused potential. When understanding the value of Building Information Model (BIM model) data as an asset leads to the question of productizing BIM models into commercial items part to product portfolio, just like tangible products.

The understanding of building information models as products is not consistent and it is even a missing concept. One reason behind the lack of the capability to see BIM as a product root from the mystification related to BIM and the failure of the whole industry to fully unleash the potential of BIM. Another reason behind it is the building industry’s overall lack of information and current practices related to productization and product portfolio management, which is hindered by the disorganized order fulfilment process practices and poor progress payment practices generally in the industry. These are seen to be one of the key causes for delays and overruns in construction projects and thus the utilization of productization should be considered as one solution to decrease the deficiencies in delays and overruns in construction projects.

The potential in both BIM and the value of BIM is recognized regardless difficulties related to understanding of BIM products. It is seen that BIM models should be evaluated value-based and the most of BIM’s hidden value can be found from the later building lifecycle phases. The value of BIM is seen to consist of the amount of data and quality of data. Thus, it is crucial to take care of the amount and integrity of the data in BIM models. This can be done by maintaining the cultural awareness of the importance of the data in BIM and the importance of the usage of BIM and creating, implementing, and following data related BIM recommendations.

For a product selling organization to commercially benefit from BIM, it is recommended to create a new product category to the product offering called **BIM model products**. Products in this category should be defined both technically and commercially in a structured manner. BIM models have multidimensional and broad knowledge structures, and their value may extensively vary based on content, format and usecases. Thus, it is recommended to use Bilal Succar’s (2009) BIM Framework firstly to separate open-access BIM models and commercial BIM model products. After doing this, it is recommended to create technical and commercial product structures for BIM models. In this, BIM Framework is recommended to be used with its three dimensions: content to which can be selected based on the case company's product offering and strategy. To succeed in productizing BIM models, the knowledge of commercial opportunity aspect of BIM must be increased among the technical BIM positions in the organization and the overall knowledge of BIM amongst the sales representatives.

In conclusion, we are on the verge of something familiar yet extremely new. BIM models are a standardized term in building industry's daily work, but only currently have they started to replace 2D-drawings increasingly. This has led to the need to take step in achieving the commercial potential of BIM and start seeing their data as an asset: considering BIM models as sellable, deliverable and invoiceable products with independent value.

5.3 Theoretical contribution

In this thesis, the product categories are divided to HW, SW and services according to Kropsu-Vehkaperä (2012), Liu *et al*. (2009). The definition of product and needs for productization are expanded according to Tolonen (2016) and Mustonen (2020) so, that product needs to be divided into commercial and technical items, of which commercial items are ordered, delivered, and invoiced in the same way. Literature regarding to definitions of product and productization within building industry is scarce, and all the found theoretical contribution of them is from Härkönen *et al*. (2018), Maloney (2002), Mansoori *et al*. (2021), Härkönen *et al*. (2018), and Halttula (2020).

The theoretical contribution to order-delivery-invoicing process comes from (Croxton, 2003) and its additions by Nguyen *et al*. (2018). The corresponding order-delivery-invoicing theories related to building industry are combination of the general definitions (Shabani & Nik-Bakht, 2021, Sholeh & Suwarto, 2020) contract type -theory by Maloney (2002), OFP-theory in construction industry by Grenzfurtner *et al*. (2020), and invoicing practices theoretical contribution (Ahmadisheykhsarmast *et al*., 2020, Grenzfurtner *et al*., 2020).

Building information model related theoretical contribution are the general definitions of BIM (Cerovsek, 2011; Halttula, 2020; Succar, 2020; Penttilä, 2006; Gao *et al*., 2015 and

AGC, 2006), BIM as product (Stepanenko, 2019; Gao *et al.*, 2015; Cerovsek, 2011; Halttula, 2020), BIM legislation, (Stepanenko, 2019), level of detail (*COBIM*, 2012; Succar, 2009), Format, Lifecycle (Succar, 2009; Gielingh, 1998) and as the most important BIM Framework theory to structure all of the BIM theories mentioned above by Succar (2009).

The theoretical contribution of this thesis questions the aspect to the current literature concerning OFP in building industry. This thesis questions the understanding of the building industry being unlike manufacturing industries. It could be criticized, if the reasons behind building industry's poor OFP practices could be understood and solved like the manufacturing industries corresponding practices have been solved. However, the manufacturing industries have also ETO and MTO practices, that are quite similar to building industry's production practices.

This thesis provides new the theoretical contribution to product and productization definitions by suggesting a new building industry object configuration; **BIM model product**, that is a data-based product type. Before, only three building industry object configurations have been presented: HW, SW, and services. The suggestion to establish a data-based object configuration in building industry opens the discussion also for the other industries about the need to understand data-based products as separate categories.

More detailed commercial productization practices of BIM model products, such as product structure of BIM models and commercial product categories of them, that are presented in this study, are the first of a kind and thus can open the academic discussion related to them. These BIM model productization theory contributions hopefully open academic discussion of the topic and moreover lead to further research of BIM models commercial aspect.

5.4 Reliability and validity

The results of the thesis can be seen applicable to the building industry. In this thesis, the literature review is observed from the general productization and OFP aspects and after that focused and compared on the corresponding practices in building industry. In the empirical study the literature review findings are compared to the corresponding of a case company. Within this thesis, only one case company is observed. Still, the productization and OFP practices are quite similar in the building industry and thus, thus, even a single case company can give significant results implicative of the current state in the wider field. The selected case company has advanced productization practices and PPM practices and PDM system already in use, so it creates an advanced example. The literature review findings of building industry's productization and OFP practices were almost identical to the findings in case study. This creates a solid ground for using the findings of the thesis in general in building industry.

As mentioned earlier, the case company has a PDM system in use unlike the majority of construction companies, that affects to the validity of the result in the sense that overall PPM, PDM and productization practices in corresponding construction companies are most likely not as advanced in the sense of PDM. This only means that in most construction companies, it can be expected that productization practices must be started from the basic level by learning the principles of PPM, especially regarding the commercial and technical product structure concepts.

In this study, it is recommended for the building industry to create a new product type in the product offering, BIM model product. It is a valid recommendation generally in the industry in since the independent value of the BIM is evident not only in the case company but in the whole industry globally. The data content of BIM is generally seen valuable; thus, it should be treated like an asset. The recommendation to use BIM Framework in productizing BIM is valid, since there are no other available examples to productize BIM models, and it offers conceptual point of view to approach BIM productization made in a structured way. BIM Framework is a flexible tool as a means of productization: its content can be changed depending e.g. on the organization's strategy and product offering, which also enables more valid product structures for each specific organization's needs. However, BIM Framework that is chosen to be a productizing tool for this study may not be the only possible option to help productizing BIM models.

A result of this study is a recommendation to divide BIM products to non-commercial open BIM models and commercial BIM model products. That is a reliable recommendation in Finnish building industry, where the laws and regulations guide some BIM models to be delivered free of charge. However, it can be applied to other countries having alike regulations. Finally, when observing the BIM product structure examples, they are valid depending on the organization's goals regarding to commercial items and capabilities regarding to technical items. The examples are built based on the general productization and product structure theory with the help of BIM Framework concept, and thus can be seen reliable to use in any other company to which intensions the type of structuring fits. Many other examples can and should be found from the product structure options of BIM models.

In this thesis, productization of BIM models is studied for the first time, and it succeeds to find means to help productizing BIM models and offering background information of the current preconditions throughout a case company. This thesis' result is valid to be used in productizing BIM models in organizations and offers great opportunities to future research on the topic.

5.5 Future research

The studies regarding to productization are still in their early stages (Härkönen *et al.*, 2015) and at the same time the unused potential of BIM is still remarkable (Mansoori *et al.*, 2021). Hence it is evident that productization practices of BIM require more research. The research can be emphasized on the pre/during productization of BIM and to the results of the productization of BIM, when there are first practices available.

The future research possibilities needed pre productization of BIM are emphasized on the general level supply chain management (SCM) and how BIM models would behave as part of it. Some of the suggestions are for example:

- immaterial rights of BIM model products
- international and national laws and standards affecting BIM models in supply chain
- international and national laws and standards affecting BIM model formats such as IFC

Another possible pre productization future research suggestion area focuses on the pricing and commercial productization as well as on technical productization and cost structure of BIM models. Concerning technical productization, some research has already been done on the product structure of BIM by Mansoori *et al.* (2021), that could be further studied and combined with BOM and attached as part of commercial product portfolio. Some suggestions to future research on the above-mentioned areas are the following:

- The financial value potential and costs of building information models
- Commercial productization and value-based pricing of building information models
- Technical productization of BIM with the PS Framework
- Technical productization and BOM of building information models

After having formed the BIM model products by using BIM Framework, and after having some practical examples and material from the building industry regarding to productization of BIM models, there are many topics that could be found interesting for future research. Some of these are related to the PDM practices of BIM products, comparison between different BIM productization strategies and researching the differences and metrics. Here are some future research suggestions:

- BIM products configurability and version controllability in PDM systems
- BIM products in order-delivery-invoicing practices
- BIM product structures and their comparison
- Differences of BIM products of various project types
- Differences of BIM products of various building types

The literature would benefit from practical examples and wider discussion on productization in general to further the productization practices and academic knowledge of productizing building information models.

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7 APPENDICES

Appendix 1: Interview questions

Question	..in Building Industry	..in Case Company	.. concerning Building Information models
1. How a product is defined ... ?			
2. What is invoiced ..?			
3. What stakeholders do need building information models and in which lifecycle phases in...?			
4. Which are the factors that create the value of building information models ....?			Is the value of building information model cost-based or value-based?
5. How productization is defined ...?			
6. What is an order ...?			
7. What is an delivery ...?			
8. How the order-delivery-invoicing practices are defined ...?			