Greener Information Systems for Product Configuration Management: Towards Adaptation to Sustainability Requirements

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Abstract: The purpose of this paper is to shed light on the need to reconceptualize the dimension of product life-cycle management systems related to product configuration to embrace data of the specific sustainability impact of the configuration choices. While this is very much related to physical products, the information systems dimension is fundamental to include to model, decide, document, trace and review sustainability of products. This paper is based on a longitudinal case study along with a comprehensive literature review. Key findings related to the isolation of product configuration systems as key determinants for specific sustainability in a governed and traceable form. These systems do largely not cover sustainability as of today: A redesign is needed. A research agenda is outlined combining sustainability-thinking with socio-technical design. A proposal for the design is presented using a multi-level, multi-tier approach to Product Configuration Systems. The process has major implications around in the industry as legislators are mandating extensive documentation for specific choices and documentation of the sustainability impact of physical products.

1 INTRODUCTION

In the current context, there is a growing emphasis on sustainability, leading to an increased demand for environmentally conscious products. This is raising a strong issue within design of information systems. Organizations are compelled to adopt more sustainable practices throughout the product life cycle (Hassan et al., 2017; Huang & Badurdeen, 2018). This shift is driven by concerns over non-renewable resource use, the obligation of strong regulations, and increased consumer awareness. During this evolving landscape, the product configuration system (PCS) emerges as a key enabler, facilitating cost-effective, customer-centric product development through tailored customization (Hassan et al., 2017; Zheng et al., 2017; Huang & Badurdeen, 2018). The importance of environmental protection and rigorous application of environmental regulations, the request of sustainable product design has become more prevalent (Badurdeen et al., 2018). This intensifies the increased tendency of mass customization and specialized customer-centric products to satisfy individual customer requirements (Zheng et al., 2017; Kristjansdottir et al., 2018). Sustainable products can be defined as manufactured products that follows sustainable principles and are sustainability compliant during their absolute product life cycle (Zheng et al., 2017). PCS consists of predefined attributes with restrictions and information related to product features, product structure, production processes, costs, and prices for customers to select (Zheng et al., 2017; Shafiee et al., 2018; Haug et al., 2019). In such a way, PCS have been defined as a socio-technical system, consisting of technical components and an organizational element involving individuals, procedures, processes etc. (Forza & Salvador, 2006). This challenges organizational sustainable design of engineered products and systems as it requires addressing both technical and organizational dimensions (Forza & Salvador, 2006; Skerlos, 2015). Although the literature related to sustainability is rich, and academia has made efforts to the conceptualization and materialization of long-

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term stakeholder value of its three pillars of sustainability: economic, environmental, and social sustainability (Huang & Badurdeen, 2018; Ghobakhloo, 2020); this supports the driving mechanism of innovation and long-term product success (Huang & Badurdeen, 2018). The major impact of sustainability impacts is normally taking place outside of the company, therefore systems and architectures must look across organisational boundaries (Tambo, 2017). The dilemma can be stated as: How can sustainable practices support PCS in engineering of highly complex industrial products? Manufacturers today are confronted with a range of diverse challenges as many configuration projects fails, as literature doesn't elaborate on strategic nor sustainable alternatives in a comprehensive way; instead, it offers broad suggestions for individual strategies with no holistic perspectives (Haug et al., 2019). Crafting a PCS demands complex technicalities or business expertise, which domain specialists may find challenging to effectively convey to configuration professionals (Shafiee et al., 2018). The challenge of representing the necessary technical or business expertise may be characterised by detailed quantification of the benefits, costs, and ROI from using PCS in the literature (Kristjansdottir et al., 2018). PCS activities focus on quotation or production processes rather than multiple business processes (Bredahl Rasmussen et al., 2021). These critiques of PCS call for a refinement for a holistic approach for an establishment of sustainable practices in manufacturing companies (Huang & Badurdeen, 2018).

Therefore, this paper focuses on identifying the PCS landscape related to the novelty of sustainability gains, excluding the product configurator is not limited to sales phases (Myrodia et al., 2019). Including the life cycle phases of a configurable product and connecting it across all business processes is considered a challenging task (Myrodia et al., 2019). Extensive literature and industrial use cases emphasize the difficulties in data acquisition and verification, valid product modelling, and accurate product documentation (Kristjansdottir et al., 2018; Myrodia et al., 2019). Interconnected information systems and digital connective information development and sharing may can challenge the triple bottom line (economic, environmental, and social) sustainability (Ghobakhloo, 2020). This paper further investigates functions for sustainability implications related to PCS. In doing so, this paper initiates a state-of-the-art content-driven review and analysis of existing literature to identify the critical elements of sustainability functions respective to PCS and its nuanced perspectives. Finally, this paper discusses the findings and justifies the fundamental design principles and sustainability trends favourably in support of PCS.

2 METHOD

This paper is based on a qualitative research approach for an in-depth case study combined with an extensive literature review and a singular case study (Dubois & Gadde, 2002; Yin, 2009). The literature review is based on the bibliometric approach (Carvalho et al., 2013). The case study is from a major European electromechanical manufacturer. The case study is longitudinal applying qualitative approach with company interviews. The case study is employed to evaluate the practical implications of the current PCS, which relates to empirical data based on the longitudinal approach of a two-year employment within the case company. The case study constructs the foundational agenda discussion based on information system within the case company (Shakirov et al., 2019).

Relevant literature and its content were based on the bibliometric approach (Carvalho et al., 2013), which primarily focus on identification of patterns within the literature based on; analysis of citations.

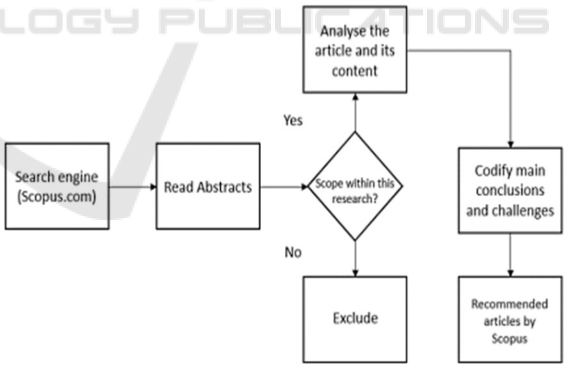

Figure 1: Literature review process.

The bibliometric study for this paper includes a content analysis, which is based on the researchers to allow the identification of the most important topics, approaches, and methods, thereby the most important definitions for this paper (Carvalho et al., 2013). To acquire a sample a database was chosen and was searched with no restrictions but by the use of keywords, such as “Product Configuration System”, “Product Configuration”, “Product Information Management”, “Product Lifecycle Management”, “Data Management Systems”, “Sustainability”, “Sustainable Systems”, and “Sustainability Evaluation”. To create transparency the workflow of the literature review is shown below in Fig 1.

3 THEORETICAL BACKGROUND

3.1 Product Configuration Architecture

The definition of product architecture yields the configuration process logically possible, without involving technical expertise (Forza & Salvador, 2006). Although, it is necessary to define system instruments to support configuration to reduce computing complexity as salesmen, engineers, and customers are within the conditions to operate autonomously in a defined configuration process (Forza & Salvador, 2006; Zheng et al., 2017).

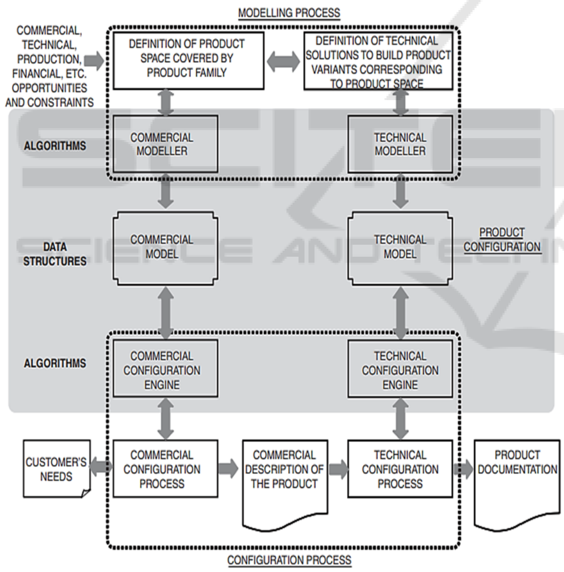

Figure 2: Logical Architecture of a PCS (Forza & Salvador, 2006).

This emphasize that the PCS and its architecture operates between function and physical domain, excluding the customer domain. Thereby, the CTO refers to product configurability, which relates to the product family architecture, where the organization has pre-defined all possible variants of components and established rules governing their determination within a product family (Forza & Salvador, 2006; Zheng et al., 2017). Product functions and purposes, along with their characteristics, are linked to individual component variants or their combinations. Although the PCS can be perceived as a computing tool that interacts with the personnel and is linked to processes: the configuration process and the modelling process (Forza & Salvador, 2006; Zheng et al., 2017). This means two uniquely interfaces related to a configuration engine and a modelling engine.

3.2 Sustainable Product Development

Skerlos, (2015) emphasize that organizations must establish their sustainability dimensions and targets based on the three pillars of sustainability (economic, environmental, and social sustainability) (Huang & Badurdeen, 2018; Ghobakhloo, 2020). These driving pillars of sustainability enforce the internal innovation mechanism for long-term product success (Ahmad et al., 2018; Huang & Badurdeen, 2018). Specialized tools are required at the product design level to evaluate the expected environmental impact of different design options (Skerlos, 2015). The importance of such tools is central as product development engineers may be challenged by conducting impact assessments for each design option without dedicated assistance (Skerlos, 2015; Ahmad et al., 2018). Literature for sustainable design serve distinct purposes, including: 1) presenting awareness about potential environmental impacts and suggesting mitigating design strategies (e.g., checklists, guidelines, and case studies), 2) enabling the ranking or scoring of a product's environmental performance concerning specific environmental aspects (e.g., toolboxes or advisory software tools), and 3) facilitating life cycle assessments (LCA) (Skerlos, 2015; Ahmad et al., 2018; Huang & Badurdeen, 2018). Skerlos, (2015) highlights that such guidelines in typical checklists conflicts with themselves or with other product attributes of the design. To address this conflict between sustainable design guidelines and to foster innovation, several application-specific software tools have emerged (Skerlos, 2015; Ahmad et al., 2018). Application-specific software tools requires less information than a full LCA, allowing ranking of design options and justification for specific decisions aimed at reducing environmental impact, they may lack the transparency of full LCAs. In addition, these tools do not capture the environmental characteristics of the supply chain and are less likely to comprehensively account for situational factors in production, use, and disposal (Skerlos, 2015). Moreover, it was found that 80% of sustainability impacts are defined within the initial stages of the product development design stage (Ahmad et al., 2018). To address this challenge in the manufacturing sector, the development and production of sustainable products have been defined as a crucial strategy to achieve sustainability (Ahmad et al., 2018). Myrodia et al. (2019) argues that Configuration Lifecycle Management (CLM) is relevant for manufacturing organizations of configurable products as the significance of CLM aims to establish a singular source for configuration data and models shared across various business units within an organization. Although, CLM refers to the management of all configuration models and correlated data across all phases of a product's lifecycle, Product Lifecycle Management (PLM) focuses on keeping track related to existing product information processes and information systems (Myrodia et al. 2019). However, CLM focuses on maintaining the PCS for generating new specifications from the PCS. Product configurator is set to model complex configurable products, where engineering rules are provided as inputs for the configurator from the PLM system. Myrodia et al. (2019) highlights the challenge of integrating product configurators with other IT systems to facilitate data exchange, as input and/or output of each configuration step. This complexity comes to IT systems utilized by multiple departments. Beyond the technical complexities of connecting, aligning, and integrating IT systems with product configurators, the operational perspective holds a significant importance and should not be discarded (Myrodia et al., 2019). The operational perspective involves factors such as process standardization, resource allocation, knowledge sharing, and supportive methods for cross-department collaboration, are crucially interconnected with the success of relevant data (Myrodia et al., 2019).

3.3 Product Configuration – Digital Solutions

Product configuration systems (PCS) are systems designed to facilitate product customization for customers (Hvam et al., 2008; Hvam et al., 2013; Kristjansdottir et al., 2018; Piroozfar et al., 2019). Such system specifies pre-defined product entities, whether these are physical or non-physical, along with their properties, fixed or variable (Li et al., 2015; Kristjansdottir et al., 2018; Piroozfar et al., 2019). The reliability and complexity of a configuration systems is reflected of the organizational product portfolio (Kristjansdottir et al., 2018). A PCS can support organizational activities of specifying product features, product performance, product costs etc. for customers during sales and engineering phases of a product (Li et al., 2015; Kristjansdottir et al., 2018; Piroozfar et al., 2019). These activities can be defined as the specification process, which involves customer needs, design, and specification of a product variant to full-satisfy customer requirements and specification of e.g., product manufacturing, supply-chain management, service delivery, product life cycle properties (Hvam et al., 2008; Hvam et al., 2013; Kristjansdottir et al., 2018). The facilitation of a PCS requires robust product information, as this is increasingly prevalent in multiple life cycles (Piroozfar et al., 2019). Activities respective to the specification process are within pre-defined attributes and well-defined complex product solutions, contradictory the goal of the customer is to find an optimal solution according to the needs, quality of specifications, lead time etc. within defined information modelled in the PCS (Hvam et al., 2008; Piroozfar et al., 2019). The configuration of the product is based on the defined solution space relative to the information modelled within the PCS. This can be referred to as customers configure-to-order (CTO), as customers defines a product within the solution space found in the configuration system (Hvam & Ladeby, 2007). Additionally, this brings substantial benefits related to generating quotations, capabilities to meet customer needs, and on-time delivery (Hvam et al., 2008; Hvam et al., 2013; Kristjansdottir et al., 2018; Piroozfar et al., 2019).

3.4 Product Configurator Development Process

The application development of configurators is a subtype of the software-based systems applicable to formalize a e.g., CTO of product specifications (Haug et al., 2012). The organizational task of developing the configurator can be complex and time-consuming, whereas Haug et al. (2012) argues that it is crucial to apply an appropriate strategy. In addition, literature lacks an in-depth exploration of various strategic alternatives; it merely offers broad suggestions for individual strategies (Haug et al., 2012). Therefore, fig. 3 is an overview related to the process of the development and maintenance a product configurator involving six phases (Haug et al., 2012). The dotted lines are not necessarily explicitly defined as e.g., the distinction between analysis module and design is not formulated with real-world practices as this involves variation in organizational practices.

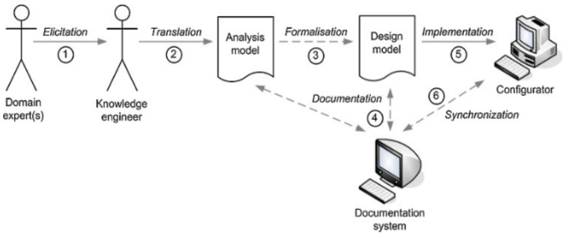

Figure 3: The Process of Creating Product Configurators (Haug et al., 2012).

3.5 Sustainable Product Configuration System

Literature represents sustainable PCS based on real-world applications for environmental accountability and product traceability within the supply chain level solutions (Helo et al., 2024). This relates to quantifying environmental impact within the PCS correlated to the organizational supply chain and its potential impact respective to their suppliers and the transportation operations. In other words, the PCS is based on emission calculations for each product variant (Helo et al., 2024). In addition, Helo et al. (2024) proposes that PCS, bill-of-materials (BOM), operations routing information, supplier locations, and environmental inventory database must be consolidated into one practical application built on industrial standards. This involves PCS, enterprise resource planning (ERP), and computer aided design automation systems merged with LCA. Borsato, (2014) highlights that PLM strategies must embrace sustainability respective to multi-disciplinary efforts by bridging product and process data beyond the organizational information system e.g., ERP, but throughout their entire supply chain. In addition, Borsato, (2014) emphasize that PLM information flows in various organizational business channels and patterns, whereas these must be linked to the current IT infrastructure and technology capabilities to exchange information and explore sustainable practices. The PLM information is relevant for sustainability purposes as the decision-making relevant for environmental issues early in the product development stage can yield more significant results, as reactive measures may prove to be less effective than proactive ones (Borsato, 2014).

4 CASE STUDY

The case company was selected based on assessment of complete access to information, data, and internal documents, as well as the availability of the existing configurator that supports multiple stages. The extension of multiple configurator processes and stages from the existing configurator, this case is reduced to industrial offerings for generalizability (Bredahl Rasmussen et al., 2021). This single-case study design can be mitigated to other case companies as an initial mapping of current PCS within the case company support several business processes and IT systems.

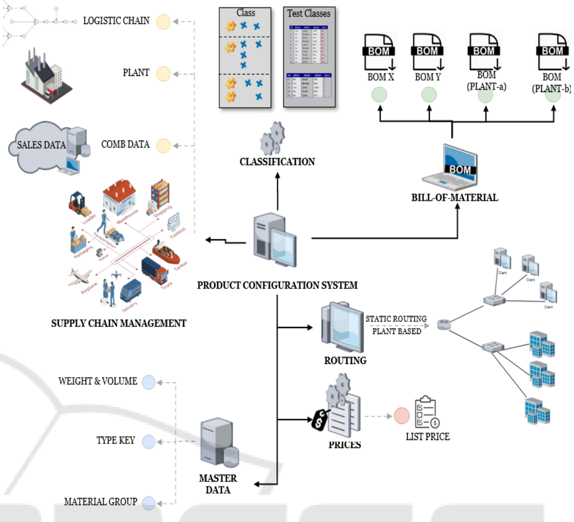

Figure 4: Product Configuration System, Case Company.

The review of the existing configuration system is applicable to investigate the conditions required for the beneficial application of understanding the sustainability perspective related to PCS (Bredahl Rasmussen et al., 2021). Fig. 4 outlines the investigated application and its conditions based on the case study of an CTO company, which provides empirical evidence of the potentiality of sustainability and the feasibility within the existing PCS. This case varies in scale of complexity as the PCS are characterized as a multistage configurator for electromechanical industrial product offerings. The formulation of a multistage configuration provides reductions at additional stages to increase the sales performance respective to improved customer communication and product quality (Bredahl Rasmussen et al., 2021). In other words, a multistage configuration includes several stages of the order-fulfilment process (e.g., quotation, product design, detailed design, manufacturing, sales areas, delivery or installation processes). The evaluation of this PCS based on a multistage configuration contributes valuable application insights into the complexities and potentialities of sustainability in diverse system excellence.

5 FINDINGS

The case company operates in various differentiated markets, where customization is highly necessary to satisfy requirements from customers, local regulations, compliance, and local authorities. The range of industrial product offerings are to accommodate specific needs to fit within existing production or process lines. The company handles the process of designing and configuring the product based on compliance from a manufacturing perspective, obtaining approval from e.g., authorities. Initially, the PCS have a broad range of standardized product family. This is as one product group for one singular standardized product offering has 10950 unique hits. In addition to this product group for PCS the product is within the range of the classification of CTO category. The number of 10950 unique hits specifying the complexity and the number of attributes that could be mixed and matched based on the large variety of product offerings. The number of attributes and constraints can be classified as a PCS with high complexity (Shafiee et al., 2020).

5.1 Exploring the PCS

This paper explores the novelty of sustainability in PCS within the case company. The exploration seeks to identify critical PCS elements of sustainability related to semantic interoperability. Considering the future sustainable industry expectations, the exploration are centralized in identifying critical aspects and potential areas in PCS layouts, this research addresses the inadequacy in academic investigations as literature related to PCS does not involve sustainability. The PCS process used by the case company consisted of six major phases: (1) Master Data, (2) Classification, (3) BOM, (4) Routing, (5) Supply Chain management, and (6) Prices. Fig. 4 illustrates the original configuration system, where the PCS is based on a multistage configurator, where product specifications are provided based on commercialized data structures related to a commercial configuration engine, corresponding to data structures related to a technical configuration engine. These computing algorithm engines are not documented nor investigated related to other IT systems.

5.2 Sustainability-Thinking in the PCS

PCS is encountered by complex real-world applications related to regulations, compliance, environmental impact evaluation. Literature link PCS and sustainability respectively for environmental accountability and product traceability within the supply chain level solutions (Helo et al., 2024). This is emphasized by the multistage configurator employing (5) Supply Chain management within the case companies PCS related to e.g., potential impact respective to suppliers, sales offices, and transportation operations. However, the technicality and subsystem with interfaces are not defined within the existing PCS. Optional sizing parameters for life cycle cost calculations is a subsystem within PCS uniquely defined product specification profile related to: operating time, energy prices, anticipated increasement in energy prices, CO2 emission intensity, maintenance cost based on a Life-Cycle-Cost (LCC) analysis. The subsystems of BOM, operation routing information, supplier locations, and sales office/areas are consolidated into the PCS design, which correlates with literature for sustainable PCS each product variant (Helo et al., 2024). However, literature emphasize the need for the consolidation for one practical application based on industrial standards. This involves the PCS to be merged with an environmental LCA database. Computing and consolidating such practical application are critically overlooked. Despite the multistage configurator involving sustainable mechanisms and resources the interface is yet to be discovered considering the investigated research literature and case results. PLM strategies are not sufficient as these case results highlights the tendency of not including multi-disciplinary efforts to bridge product and process data beyond the organizational information system.

In addition, Borsato, (2014) emphasize that PLM information flows in various organizational business channels and patterns, whereas these must be linked to the current IT infrastructure and technology capabilities to exchange information and explore sustainable practices. The PLM information is relevant for sustainability purposes as the decision-making relevant for environmental issues early in the product development stage can yield more significant results, as reactive measures may prove to be less effective than proactive ones (Borsato, 2014).

5.3 Sustainable Socio-Technical System Analysis

Sustainable Socio-Technical System (Forza & Salvador, 2006; Skerlos, 2015) challenges organizational sustainable design of engineered products and systems as it requires addressing both technical and organizational dimensions. The adoption of sustainable practices related to PLM (Hassan et al., 2017; Huang & Badurdeen, 2018) concerns the obligation of severe regulations and environmental product declarations (EPD) as manufacturers must report comparable and third-party verified data like environmental performance of their respective products (Environmental Product Declarations, 2024). The formulation of a multistage configuration (Bredahl Rasmussen et al., 2021) is set to increase sales performance relative to product quality, where EPD the environmental performance of each configured product must be described based on LCA of each configured product in the PCS based on ISO 14020 (Environmental Product Declarations, 2024). The implementation of LCA relates to information compiled in a EPD reporting format and ISO 14020 conjunctions, which leads to customer-centric product development through tailored customization based on sustainability-thinking. Predefined PCS attributes and information related to product features, product structure, production processes, costs, and prices for customers to select shall be verified by developing a EPD subsystem that corresponds to PLM activities, PCS functionalities, and with other standards in the ISO 14020 family. The case company focuses on operational excellence based on LCC analysis that relates to operational sizing parameters in the PCS, relying on investment-risk of a product beyond its initial acquisition expenses. This paper supports a holistic approach to integrating sustainability-thinking leading to a sustainable PLM generation, emphasizing the implementation of ISO 14020 and EPD reporting elements with a renewed PLM and PCS focus on representing sustainability-thinking based on real-world applications for environmental accountability and product traceability. The emphasis correlates to quantifying environmental impacts on understanding the considering facilitation of ISO 14020 and the information system driving products through standardized declaration methods.

5.4 Bridging Sustainability-Thinking with PCS

The theoretical background of the process of developing product configurators introduces the concept of CTO product specifications (Hvam et al., 2008; Haug et al., 2012).

The complexity of integrating sustainability-thinking lacks an in-depth exploration based on PLM strategic alternatives. Therefore, Fig.5 follows the process of the development and maintenance of a product configurator (Haug et al., 2012), which

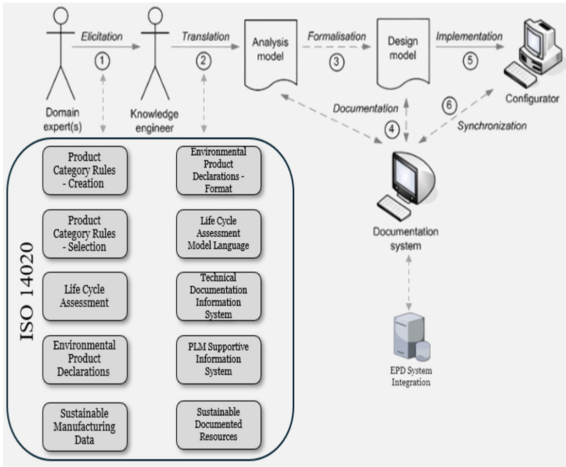

Figure 5: ISO 14020 Configuration System Integration.

considers the importance of sustainability-thinking respective to EPD systems and ISO 14020 compliance. The real-world application of Fig.5 does not account for schematic foundational algorithms programming of optimized sustainable practices. The growing importance of sustainability concerns the attention of introducing sustainable PLM to support processes related to the practicality and credible modelling of
optimized sustainable footprints by changing sustainable documented resources.

5.5 Information Architecture Proposal

The proposed information architecture is based on Forza & Salvador, (2006) and Haug et al., (2012) for a sustainable socio-technical architectural information system of a PCS.

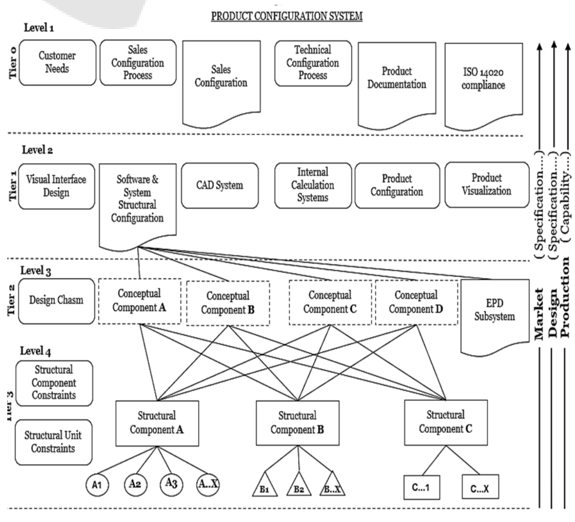

Figure 6: Proposed IS Architecture.

The sustainable socio-technical architectural information system is modularized according to patterns of hierarchy, defining the basic concept for how to bridge sustainability-thinking with PCS. The proposal establishes the layout and integration relationships of structural components and units for the software PCS items. In addition, the architecture is comprised into several structural units, which is connected and integrated into structural components. Structural components and units are product elements that can be managed through e.g., LCA. Structural components are combined into multiple conceptual components, which enables the software of the PCS to be utilized. The information for a sustainable socio-technical system requires the adoption of PLM practices related to obligations of strict regulations of EPD. This information is a dynamic interaction between the company and the customer as this interaction is fundamentally important as manufacturers must report product compliance and environmental performance. The product specifications and characteristics are defined by the customer, explored in the customer interface. Fig. 6 considers the importance of sustainability-thinking regarding product specifications to satisfy customer needs through configuration activities respectively if the product variety offered is compliant with ISO 14020 based on the information system connected to the EPD subsystem. Additionally, the proposed information architecture improves the transparency and efficiency of front-end communication as sustainability opportunities becomes transparent for customers to decides.

5.6 Research Agenda

The findings in this paper it is expected that ISO 14020 provides a foundation for environmental declarations, and product categories rules (PCR) development can be combined with detailed and specific rules for PCS and PLM strategy dimensions. Moreover, to ensure organizational consistencies and reliability in environmental information systems. Properties of sustainability-thinking broadens the vocabulary of promoting sustainability and information systems respective to environmental impact of products in the context of PCS and PLM. The properties of this case study revealed a differentiated understanding between what existing literature defines as sustainable PCS and what is expected to be uniformed and compliant with distinctive sustainability-thinking for PCS. Through research Fig.6 summarizes a proposed research agenda to share experience based on real-world applications into the sustainability-thinking domain.

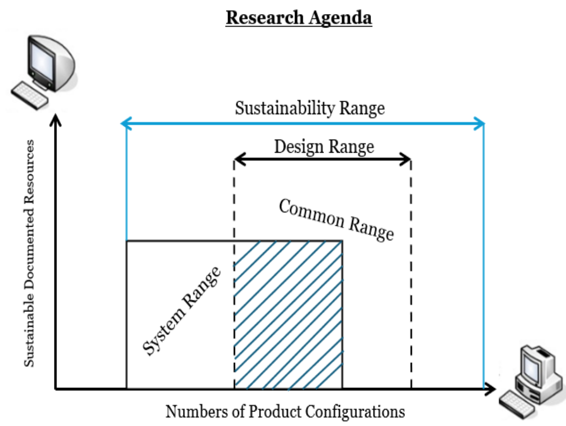

Figure 7: Proposed Research Agenda.

6 CONCLUSIONS

This paper acknowledges that sustainability in Product Lifecycle Management (PLM) is an ongoing discourse rather than a concluded enterprise system, and the information system respective to engaging a meaningful conversation is yet to be explored (Forza & Salvador, 2006; Hvam et al., 2008). The primary emphasis relates on the aspect of modelling and fostering alternative mindsets of sustainability-thinking that goes beyond sustainable manufacturing and sustainable product development (Hassan et al., 2017; Huang & Badurdeen, 2018). The case study results emphasize that that the most significant risk associated with sustainability is reducing it to a mere reporting tool as the system complexity increases (Bredahl Rasmussen et al., 2021). There are undefined tolerances of facilitation where sustainable PLM goes beyond reporting, aiming instead for practical and credible modelling of optimized sustainable footprints through the adaptation and utilization of well-documented sustainable resources (Hvam et al., 2008; Hvam et al., 2013). The research agenda emphasizes that constraining sustainability initiatives to a superficial undertaking solely aimed at generating reports is cautioned against. This intricate research necessitates continuous dialogue and collaboration to effectively implement sustainability initiatives in practice.

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