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Published in:
Procedia CIRP

DOI (link to publication from Publisher):
10.1016/j.procir.2021.11.005

Publication date:
2021

Document Version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Nielsen, M. S., Andersen, A-L., Brunø, T. D., & Nielsen, K. (2021). Modularization Across Managerial Levels and Business Domains: Literature Review & Research Directions. *Procedia CIRP*, *104*. https://doi.org/10.1016/j.procir.2021.11.005

Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 104 (2021) 3–7

www.elsevier.com/locate/procedia

54rd CIRP Conference on Manufacturing Systems

Modularization Across Managerial Levels and Business Domains: Literature Review & Research Directions

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Abstract

Modular system architectures in both product and manufacturing domains are of high interest in both academia and industry, as having modular product platforms and reconfigurable manufacturing systems are a key enabler for companies to obtain the strategic flexibility needed to respond to rapidly shifting market and customer requirements. Previous research has focused extensively on modularizing products and manufacturing equipment. However, to fully reap the benefits of modularization, this cannot be treated solely as engineering efforts taking place in one domain or cross domains with co-platforming, but rather as a top management initiative. The purpose of this research is to review state-of-the-art literature on modularization/platforming looking across managerial levels and business domains, market, product, and manufacturing.

Keywords: Management; Modularization; Strategic Flexibility; Platform Development

1. Introduction

For many of today´s manufacturing companies, competition has intensified as customers are demanding more customized products with shorter life cycles at a lower cost [1]. In response to these new versatile market requirements, manufacturing companies have introduced modularization as defined by Miller [46] as an enabler for obtaining the strategic flexibility needed to survive and stay competitive [2,3]. Product modularization was initially introduced in the 80´s by computer manufacturers as an enabler for personalized computers and was quickly imitated by other industries such as the automotive and electrical appliance industries [4-6]. Because these highly personalized products needed to be produced in smaller and often fluctuating volumes, manufacturing companies introduced the concept of Reconfigurable Manufacturing Systems (RMS) in the late 90´s [7,8]. With the introduction of modularity as an enabler of rapid functionality and capacity reconfiguration, the foundation for truly modularized companies was laid. In the last 20 years, both research and industry has focused extensively on modularization and platforms in both product and manufacturing domain [9]. However, to fully reap the benefits of modularization in manufacturing companies thereby not only managing but also capitalizing on increasing product variety, modularization and platform development cannot solely be treated as an engineering effort in product and manufacturing development. Rather, modularization should be targeted as a strategic and top management initiative [10].

To address this, the purpose of this research is to review state-of-the-art literature related to modularization across managerial levels and business domains to identify tools and methods to be used when organizing and managing these modularization initiatives. In order to classify these tools and methods according to what business domain and on what managerial level these belong, two overall objectives are stated

10.1016/j.procir.2021.11.005

for this research: classify literature across different business domains and identify knowledge gaps in modularization at managerial and planning levels.

The paper is structured as follows: The second section presents the methodology used to collect relevant literature for the review, the third section describes the classification frameworks and definitions used through this paper, while the fourth section presents the classification of literature in accordance with the frameworks and definitions presented in section three. Conclusively, the main findings are discussed, and further viable direction for research are presented.

2. Methodology

In order to address the objectives, a systematic literature review is conducted by following three overall steps: retrieval, exclusion, and classification [11]. In order to identify as much relevant literature as possible for the review, a search strategy was applied in two search databases (Web of Science and Scopus). To identify relevant key words for the search string, four papers were used as inspiration [12-15] as each of these was found to be relevant within each domain and across managerial levels. Based on these four papers, a list of relevant keywords and topics were created and synonyms were found to be used in the search. The search string was created for Title, Keywords and Abstract searching and included: *Platform* Near/3 *Development* OR *Integration* OR *Architecture* OR *Product* OR *Family* OR *Module* OR *Modular* OR *Design* OR *Portfolio* OR *Reconfigurable* AND *Research* OR *Engineering* OR *Methodology* OR *Approach* OR *Management* OR *Strategy* OR *Information System* OR *Market* AND *Market.* No time frame for relevant paper was set, but only papers in English were included. Moreover, the search was limited by research domains, which were set to include: Engineering, Computer Science, Mathematics, Business- Management & Accounting, Decision Science, Energy, Materials Science, and Economics-Econometrics & Finance. This search gave respectively 924 paper in Web-Of-Science and 1003 papers in Scopus, which were included in the initial process of excluding irrelevant material. The first exclusion process was conducted by screening paper titles, resulting in 208 papers form Web-Of-Science and 117 papers from Scopus. These remaining papers were included in the second exclusion process consisting of a more thorough examination of the remaining abstracts. From this second screening, 47 papers remained. Based on additional forward and backwards searches, 24 additional papers were added to the list, resulting in a final list of 71 papers included in the literature review. Because of manuscript space limitations, only a limited number of papers from the literature review is included in the paper references. However, the findings, the discussion, and overall conclusion of this research build upon all 71 papers. A full literature list of reviewed papers and the classification protocol can be provided by authors upon request.

3. Classification Framework and Definitions

To get an overview of modularization initiatives across different business domains, the reviewed literature is firstly classified according to the business perspectives; market, product, and manufacturing [16]. This is done to identify literature within each of the specific domains and in the cross section between domains, see Figure 1. In order to identify whether literature would be classified into either the market, product, or manufacturing domain these needed to be defined. In this review the domains are defined as the following. Literature is classifed in the market domain if it is concernced with or discussing the competitive factors e.g: price, quality, speed, or innovation as defined by Slack [17]. Literature is classified in the product domain if it is concerned with or discuss design or creation of prodcut architectures. Literature is classified in the manufacturing domain if it is concerned with or discussing the design or creation of manufacturing system arcihtectures. After the literature has been classified according to business domain further classification in accordance with managerial/planning level is performed. In this context the, literature is classifed on a strategic level if concernd with one of the three main components of strategic logic: Business Concept, Organization Concepts, or Core Processes [18]. The tactical level is concerned with the development of modular architectures, in both the product and the manufacturing domain, and how these are affected by the market in the development process. The operational level is concerned with the deployment of the product and manufacturing architectures as specific products and manufacturing systems for specific markets. While classifing the literature according to managerial/planning level, some papers could be classified on more than one level as they could concern topics that are relevant on both levels.

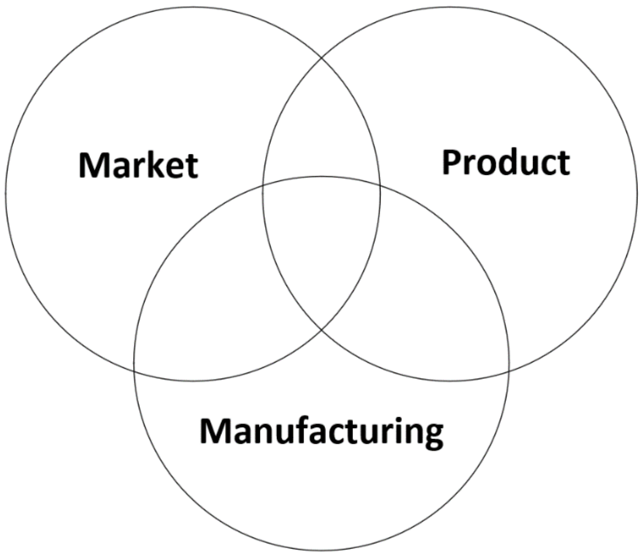

Figure: 1. Business domains and their cross sections.

4. Classification of Literature

When classifying the literature according to business domains in Figure 1 it was possible to allocate 62 papers to one specific domain or in cross-sections between domains. The remaining 9 papers that did not allow for classification were more generic literature on modularization or platforms [19,20] and papers performing post-project case research [6]. After the literature classification according to domains, further classification according to managerial/planning levels was performed. In this classification, the reviewed literature could appear in more than one of three levels as some literature represented research topics across multiple levels.

In Figure 2, the total sum of papers allocated to each domain and cross-section is reported. In this review the literature has been classified in the following way: 24 papers were identified in the product domain, 6 papers were identified in the manufacturing domain, 1 paper were in the market domain, 18 papers were identified in the product/manufacturing domain, 10 papers were identified in the market/product domain, 3 papers were identified in the market/product/manufacturing domain, and 0 papers were identified in the market/manufacturing domain.

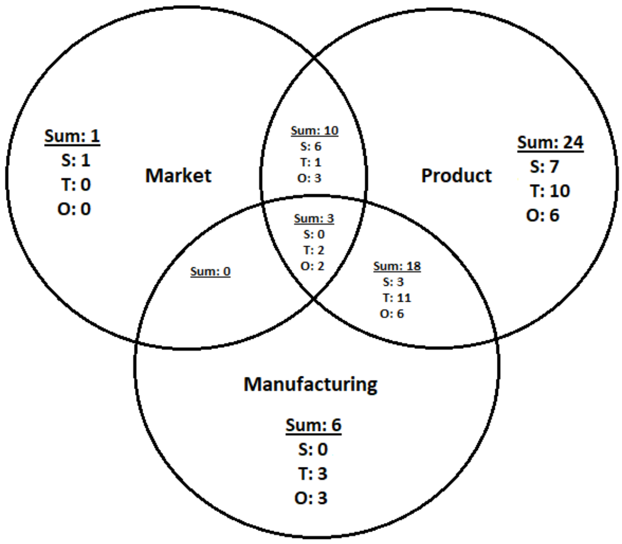

Figure 2: Classification of 62 papers, S indicating strategic, T indicating tactical, and O indicating operational.

This classification indicates that research on modularization primarily is related to the product domain and its relation to both the market and manufacturing domains. Moreover, it is evident that with 24 papers classified within the specific domain of product architectures, a higher number of papers exists on all three managerial levels than in the other domains. This could be caused by the strategic drives that are mediating the link between product architecture and organization architecture [10,21]. On the strategic level, most literature is anecdotal [21-24] and mostly build upon analyses and discussions of industries with a high level of modularization such as computer, automotive, and household appliance. Murray et al. [21] propose three modularization arenas: Modularization-In-Design, Modularization-In-Production and Modularization-In-Use. According to Murray et al. [21], a company`s strategic direction should depend on which of these modularization arenas the company has chosen to compete in. Ulonska et al. [25] propose a step-by-step methodology using product and variant maps to structure and analyze product variant information for future configure-to-order strategies.

On the tactical and operational level, different methods with the overall objective of designing the optimal product platform are described. These methods are primarily quantitatively oriented as methods such as fuzzy goal, mixed integer, and liner programming are proposed as methods for finding a near optimal number of platforms to minimize production cost [26-28]. Other mathematical methods are similarity indices [29,30], where ElMaraghy et al. [30] propose a Decision Support System (DSS) for product platform design and selection in high variety manufacturing. Likewise, Anggraeni et al. [29] use similarity indices for comparison in the conceptual phase for developing new product variants.

In the cross section between the product and manufacturing domain, almost the same amount of papers (18) has been classified as in the product specific domain. This could be caused by academia´s focus on co-platforming in recent years [31,32]. However, in this group of literature, most of this has been classified to be on the lower managerial levels with 11 papers on the tactical level and six papers on the operational level. Only 3 papers were classified on the strategic level, where e.g. Løkkegaard et al. [33] propose a method where the modeling of business critical design rules and design principles could be used as a framework when introducing new architectures and Michaelis et al. [34] propose a set-based concurrent engineering method for formulating the bandwidth in functionality and performance for future architectures.

As it was found on the tactical and operational levels in the product domain, most of the methods identified on the tactical and operational levels in the cross-section between the product and manufacturing domains are also found to be primarily quantitatively oriented and model based. Here Levandowski et al. [35] propose a method for facilitating model-based producibility assessments of product variants in the early assessment of platform concepts and Abbas et al. [32,36] use mixed integer linier programming to setup a mathematical model for comparing the core product characteristics with manufacturing equipment capabilities. However, Andersen et al. [9] identified key challenges such as the need for new organizational setup and responsibilities, and knowledge and capability management in order to enable successful co-development between product and manufacturing domains.

In the cross-section between the market and product domains 10 papers have been classified with six on the strategic level. Here Sanchez [10,37] investigates the impact of modularization on two of the main concepts of strategic logic, Organization Concept and Core Processes. Sanchez suggests that the creation of modular product architectures enables the creation of loosely coupled, flexible and modular organizations structures thereby reducing the need for much overt exercise of managerial authority across organizational interfaces. With this reduction of managerial intensity and complexity in product development, Sanchez argues for a greater flexibility in product creation projects. However, Sanchez [38] also finds that these new loosely coupled product and organization architectures require new concepts for managing knowledge and organizational learning. On the tactical level, ElMaraghy et al. [39] propose a mathematical model to index and evaluate current products diversification and degree of diversification in respects to market requirements. On the operational level Zhang et at. [40] propose a method for optimizing existing product platform based on market requirements identified using the Kano model.

In the manufacturing specific domain, only six papers have been identified, with no papers classified on the strategic level. On the tactical level, Francalanza et al. [41] proposed a method for selecting the level of changeability in Reconfigurable Manufacturing Systems based on the uncertainty in product evolution and Soerensen et al. [42] proposed a stage-gate approach to brownfield platform identification and development. On the operational level, ElMaraghy et al. [43] propose a framework for modeling Reconfigurable Manufacturing Systems using agent-based and discrete-event simulation to address the required capabilities of the Reconfigurable Manufacturing System to handle the expected changes in product architectures.

In the cross-section between all three domains, only three papers have been identified. On the tactical level, Fixon [44] proposes a method of using functional component maps and matrixes and product architecture maps to link product, manufacturing, and supply chain design decisions. On the tactical level, Jensen et al. [45] propose the corporate platform, linking market, product platform, manufacturing, and product development, as a way of aligning the product references with the company´s references.

In the market domain, only one papers on the strategic level were identified. Here Tsvetkova et al. [3] argue that a company´s business model can become more flexible with the help of modularization in its value proposition, revenue model and capabilities. However, in this research, the context is the entire ecosystem and not the specific company.

5. Discussion

From the classification of literature, it is evident that a large portion of the reviewed papers are related to the design of specific modular product and manufacturing architectures [32,39]. These activities are found to be mostly on the lower managerial levels in the business domains related to product and manufacturing as these are often specific design tasks performed in specific projects. However very limited research has been conducted on how these initiatives should be governed through strategic initiatives covering a wider range of business domains. Sanchez [38] argues that success or even survival for manufacturing companies in highly dynamic product markets depend on more attention from strategic management to modular, products, organization, and knowledge architectures. Baldwin & Clark [2] state that leadership is critical in providing a framework which should include a strategy, for the organization to follow in the process of reaching the goal of strategic flexibility through modularization. Therefore, there seems to be a gap in research on how modularization initiatives should be rooted in companies' strategies and what this mean. Strategic management is concerned with the development of a company´s: business concept, organization, and core process [18]. However, only very little research exists on how modularization affects these. The literature classified in this review uncovered various methods for developing modular product and manufacturing system architectures, which is part of a company´s core process, however, none of the classified literature investigates how these methods impact a company´s internal governance structure in development projects. Traditional development projects have been treated as one-offs with a fixed time period, budget and incentives. However, when developing either modular product or manufacturing architectures, these governing methods have been found to cause problems. When system designers and project managers are faced with incentives such as minimizing development cost of the specific system and completing the project within a specific time frame, there is a lack of incentives from system designers and project managers to absorb the additional cost and time in designing a platform.

6. Conclusion

Modularization in some form, whether it is as product platforms or reconfigurable manufacturing systems, has been widely accepted as an enabler for obtaining the strategic flexibility needed to stay competitive in today´s turbulent markets. This review has through classification of literature investigated in which business domains and on what managerial level research has been made to assist in obtaining this strategic flexibility. Moreover, research within the areas which have received the most attention from academia have been analyzed, and the findings of this analysis support the notion that lower managerial level mostly deal with tools and methods used for specific design decisions while tools and methods to be used in the higher managerial level have not received much attention in academia. The scarce literature that does address the higher managerial levels stress the importance of addressing modularization on this level, indicating a significant literature gap in order to provide knowledge and methods to industry to be able to do this. Therefore, future research should focus on tools and methods that could be used when companies in the future should set a strategic direction for modularization initiatives, as well as linking this to the lower managerial levels to implement the strategy.

Acknowledgements

The authors of this paper would like to thank professor R. Sanchez for his valuable guidance and constructive suggestions during this research.

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