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Industrialization in Construction Companies—A Benchmark Study on Manufacturing Companies

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Abstract: Productivity has been modest in construction due to many reasons, especially project-specific operations and fragmentation. The main aim of this research is to map the challenges toward industrialization in construction through a comparative study of the manufacturing industry. An inductive approach and a qualitative method are followed by applying semi-structured interviews and node-based thematic analysis. The key elements of industrialization in mature manufacturing companies are benchmarked. The findings indicate a specific order of steps for industrialization in construction. Data and information management with achieved systematization have been sources of productivity in manufacturing companies. However, the systematization starts from the offering, and construction companies need to define their offering, that is, their products, and define their respective data. Only accurate and good quality data on products enable the systematization of order delivery processes, which are the engine for a company's success or failure. Continuous efficiency improvement is only possible with systematized processes and the respective data related to these processes. The originality involves clarifying the industrialization of construction companies via products, respective data, and processes, considering industrialized manufacturing companies.

Keywords: predefined products; predefined processes; data management; industrialized construction

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1. Introduction

The construction industry has suffered productivity challenges for a very long time. However, there has been recent interest in the digital transformation and industrialization of construction to respond to these challenges. Industrialized construction refers to standardizing building processes and product parts and is characterized by using product modules with high levels of predefinition [1] and recurring processes in the construction company's production and supply chain, supported by information flow and continuous improvement [2]. Off-site construction, prefabrication, pre-assembly, and modular construction are interchangeable terms used to describe the main approaches in industrialized construction [3]. Industrialized construction requires comprehensive process planning, control, and tightly connected design and operation management [4]. Such approaches are strategic by nature and affect the business. The construction industry has recognized that applying these industrialization principles increases productivity [5], reduces construction costs and production time [6], and positively affects site operations [7] compared to traditional building methods.

Despite extensive research on information flow [8,9], processes integration [10], and communication and coordination [11], our understanding of why digitalization and data management are not fully embraced in construction and how to apply the approaches to facilitate the industrialization of construction remains limited [3]. Nevertheless, the digital transformation and adoption of industrialized working methods have been rather slow on a practical level, and, to some extent, change resistance has also occurred [12]. More than implementing discrete digital technologies is required [13].

The operation model describes how business strategies and models are executed at a practical and more detailed level [14,15]. The industrial operation model is an integrative approach commonly used in manufacturing companies like Boeing and Toyota in their production system, enabling the utilization of the scale of benefits [16]. In construction, the operation model has traditionally followed the so-called "prototype model" where the end-products are "let be" unique [2]. Uniqueness relates to the project-based approach, however, leading to several challenges in productivity. This approach differs from traditional engineering-to-order because it does not aim at systematizing the operations. The full potential of industrialization is currently not being leveraged in construction, nor is the potential of digitalization in this context fully understood.

Some industrialized construction companies, such as Lindbäcks, BoKlok, and BONE, operate according to a business strategy and operational structure that differs from that of traditional construction companies [17,18]. The industrialization of construction is seen to require a drastic shift in the operation model [19], including creating a shared understanding among distributed teams [20] and implementing efficient and streamlined processes to obtain expected outcomes [21]. Companies should pay attention to operations while formulating strategies [22], as operations are the profit-generating engine [23]. Evidently, industrialization, including information management, has created benefits and productivity improvements in the manufacturing industry [16]. Respectively, construction has not been able to realize this potential. Therefore, this study aims to understand the differences between industrialization and its elements in the manufacturing industry and to compare these to the findings from construction. Ultimately, our study aims to provide a transformation model for industrialization in construction companies. The above discussion can be framed into the following research questions (RQs):

RQ1: What are the challenges of industrialization in construction companies compared to the industrialization status in manufacturing companies?
RQ2: What are the development steps and content in the transformation toward industrialization?

First, the literature is reviewed to identify key elements of industrialization and link data and information management into the context. The identified elements will be assessed in two contexts: benchmark manufacturing companies, where the essence of industrialization is better conceived and forms an inseparable part of operations; and construction companies on the path to industrialization. Based on qualitative interview data, we develop transformation steps for construction toward industrialization. Finally, the findings and implications are discussed, and the paper concludes.

2. Related Research for Industrialization of Construction

Construction has suffered from low productivity for decades [24]. The situation seems particularly bad when construction is compared to the manufacturing industry or high-tech industry. This does not mean that there has been zero development in construction but that the input has grown more than the ratio of the output, where productivity is output divided by input [25]. Productivity can also be divided into internal efficiency and external effectiveness [25], where internal efficiency refers to internal processes and effectiveness to external deliverables for customers.

Perhaps one of the most referred-to concepts of efficiency can be found in the Toyota Production System (TPS), also called the Lean production system. The ultimate purpose of the original TPS is to find the most efficient way for the production process, regardless of whether it is a partial process of one company or a system of generating value for the entire supply chain [16,26]. There is a great amount of research on Lean and its application to different industries. Lean can be approached from many different perspectives and in many ways. One of the most practical and utilized approaches was described by Womack and Jones [27] as the following five Lean principles: (1) defining value (what needs to be delivered to customers), (2) mapping the value stream (what is the process that delivers the defined value), (3) creating flow (what are value-adding activities in the flow of delivering the value), (4) using a pull system (pulling the value, when needed), and (5) pursuing perfection (the continuous improvement of value and flow).

Fragmentation can be considered one of the most significant challenges in construction in the way toward industrialization [28]. It emerges both horizontally and vertically. Horizontal fragmentation means that the value chain is split into many phases that are typically managed by different operators and organizations. Vertical fragmentation means splitting the value creation process or flow into, for example, heating, ventilation, air conditioning, automation, etc., in construction [29]. The resulting decentralized control model is one in which no one has an interest in controlling the whole. In turn, every interface has points of discontinuity, where interruptions to the flow of information occur, and in these, one prepares for risk, and risk also has a price, not to mention a lack of trust in the value chain.

Project orientation and systems and short-term contracts hinder the smooth operation of value chains in construction [30]. The project orientation is challenged in process systematization as almost every process is created from scratch for every project [14]. This makes continuous improvement challenging and hinders process repetition [31]. The lack of repetition results in the difficulty of measuring the process status, setting development targets, and measuring the impact of development actions. Variance in processes in response to project requirements makes optimization and systematic improvement challenging [32]. This hinders possibilities for economies of scale [2] despite the processes being similar among projects, with only the content changing [4]. Between different types of project contracts (e.g., design-bid-build, integrated project delivery), it is also essential to pay attention to the process ownership and related training in line with organizational development strategies.

There is, however, research on the fundamental aspects of industrialized construction operations. According to Lessing [32], the prefabrication of building parts, technical and IT systems, the planning and control of processes, continuous improvement (CI), the reuse of experiences and metrics, logistics, and long-term relations are critical elements of industrialized construction. Annunen and Haapasalo [2] present an industrial operation model consisting of product, data, and business processes enhanced with CI.

In industrialized construction, the level of industrialization affects the level and nature of project-specific work and relates to the level of predefinition in terms of products, ranging from traditional project orientation to completely predefined products [18]. The transformation from traditional construction starts from a strategic and business model level, while processes are the profit-generating engines [22,23,33]. In addition to business processes, the offering of products—the definition of deliverables—is one of the key elements in business models [34]. One of the great difficulties in construction is cost-based pricing as a common revenue logic applied in construction businesses.

Repetitive processes enabling continuous improvement, the reuse of experience, and performance measurement are another distinguishing feature of industrialized construction compared to project-oriented construction [32]. Repetitive processes also enable the operationalization and control of the business model [35]. The typical operations of a company consist of a process for product development and a process for delivering customer orders [34]. Given the project orientation, construction is challenged in process systematization as almost every process is created from scratch for every project [14]. This makes data reuse challenging in construction and hinders process repetition [31]. The lack of repetition causes difficulty in measuring the process status, setting development targets, and measuring the impact of development actions. The variance in processes in response to project requirements makes optimization and systematic improvement challenging [32]. This, again, hinders possibilities for economies of scale [2].

The systematization and standardization processes and product offerings will ultimately lead to industrialization in the construction industry [1,30,32,36]. A prerequisite for processes is a well-defined product and offering [37], enabling the prefabrication of components or modules of a building through product design and development [32,38,39]. The predefined product structure precedes modularization and configuration. The benefits of modularization include possibilities to manage variations in product shape and function whilst enabling standard component design, production, and modules within a product family [40–42]. Hvam et al. [43] demonstrate levels of product predefinition from typical project-oriented engineered-to-order products to fully specified standard products where the customer selects an existing variant. In industrialized off-site construction, the idea is to achieve standardized products with minimized project specifications [18]. The predefined product improves the predictability and stability of the business processes [44], reduces the manufacturing complexity enabling repetitive units [45], reduces delivery time [44,46] and production costs [47,48], and improves quality [49].

An organized product structure enables product data management, resulting in the utilization of digital data management tools and methods. For a defined product, data should be definitive (master data) and structured in line with the shared business goals of the business processes [50]. However, the lack of a well-designed transactional structure, problems in the reliable exchange of information, a lack of system integration, and stakeholder challenges hinder full BIM utilization [51]. A predefined standardized product structure was proposed as an information repository and seen as the missing link between the BIM approach, disconnected construction processes, and information systems [52,53].

Effective, integrated data management systems are needed to reap the potential efficiency gains enabled by predefined components [54]. Building Information Modeling (BIM) relies on effective data management while providing a digital platform for creating, managing, and sharing detailed information considered crucial [55] to improve inefficiencies in the construction industry [56,57]. BIM plays a role in component production consistency [58] and productivity [59,60]. Its promise includes opportunities for improved information exchange and knowledge management [61] and enhanced executive effectiveness [62]. Additionally, the benefits of 4D, 5D, 6D, and 7D BIM utilization in integrated data management are considered valuable in the industry [63].

The above-mentioned challenges in the construction industry are compiled in Table 1, and similarly, the lessons learned from the manufacturing industry as tentative areas relieving these challenges are summarized in the same table. Products, processes, data, and information systems are the main enablers of performance improvements and industrialization, according to the earlier literature. They are closely interrelated and play important roles in optimizing and shaping industrial operations, and one cannot exist without the others. A predefined product offering emphasizes the utilization of data related to deliverables in a construction process or project. Product data, in turn, enable the systemization of the construction process or parts of it, incorporating, for example, vendor data to product data, leading further to an as-built data model [64] and finally even resulting in digital twins. These elements of industrial operations can be seen working in the manufacturing industry [2,50] but are not yet fully utilized in the construction industry [51]. Therefore, our study aims to deliver a comparative study of these elements between manufacturing companies and construction companies.

Table 1. Summary of the challenges in the construction industry and tentative solution areas in the manufacturing industry.

Challenge in Construction Industry	Tentative Solution Area in Manufacturing Industry
Horizontal and vertical fragmentation of the value chain and the value creation process	Process-related improvements
Project orientation and systems and short-term contracts hinder process systematization	Process-related improvements
Cost-based pricing as a common revenue logic	Process- and product-related improvements
Lack of reused parts and modules	Product-related improvements
Lack of systematic product and service development processes	Product-related improvements
Low level of industrialization and utilization of predefined modules	Product- and data-related improvements
Fragmentation hinders data utilization	Data-related improvements
Diversified and poor data quality	Data-related improvements

3. Research Design and Methodology

The main aim of this study is to analyze, based on the earlier literature (Figure 1), the main challenges of industrialization in the construction industry and compare how these challenges have been solved by manufacturing companies. Our study is qualitative in nature, based on interviews with selected construction and benchmark companies. Based on the findings from interviews and comparative analysis, our study aims to provide the transformation steps for industrialization in construction companies. In detail, our study follows an inductive approach and a qualitative method [65] and the basic logic of case studies [66] as inductive research offering a systematic yet flexible approach to knowledge generation where exact information is not yet available. The unit of analysis is a company-level product, data, and process. To advance our understanding of the elements of industrialization and their potential to facilitate the industrialization of construction and the potential of digitalization, key elements are explored from the main contractor's ("main contractor" typically refers to the primary construction company or organization responsible for overseeing and managing a construction project) perspective since main contractors are the stakeholders who finally accumulate the cost of construction or result in cost savings for the entire project. In other words, the main contractors are responsible for manufacturing in construction. This is also the fundamental reason why mass production manufacturing companies were selected as a comparison for benchmarking to outline the potential existing in industrialization for construction.

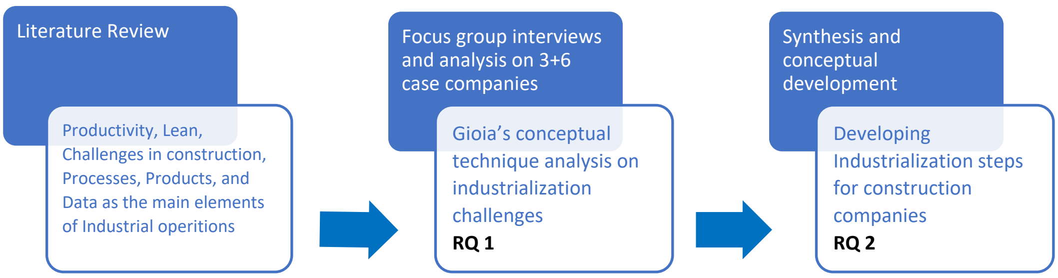

Figure 1. Research process.

With the created research framework from the literature (product, data, and process), we have generated a questionnaire for semi-structured interviews [67] (Appendix A). The interview was also divided into three sections, processes, products, and data, carefully following the identified key elements of industrialization. Interviews were conducted using a focus group interview method [68]. The main advantage of focus group interviews is the purposeful use of interaction that enables discussion and develops attitudes to generate data. This is important in an inductive approach when predefined questions may not be fully accurate or cover entirely the area of research. However, the disadvantage of dissenting individual voices was noted and covered by interviewers, with detailed questions for quieter interviewees [68].

The selection of the nine companies was carefully considered and aligned with the research objectives. The intention of the benchmark was to identify successful practices utilized by companies with established procedures that could be customized and implemented by construction companies to enhance their performance. Three advanced industrial manufacturing industry companies were selected as the benchmark companies (Table 2). The original selection for three benchmark companies was based on their expertise in scaling up international business with recognized business efficiency. These companies were selected due to being advanced in their operations and having established the configure-to-order mode of process and the respective data management practices. In addition, very open access to these companies enabled their ability to collect rich data. Six construction companies were selected because of their main contractor role in the construction process comparable to manufacturing in the benchmark companies. These companies are on their way to industrialization (Table 2) but still operating mainly in the engineer-/design-to-order mode. These companies were very open to participation as they have interests in industrialization development, and they already had evidence of developing some industrialization practices in their operations. Within these six construction company interviews, the last two interviews did not provide novel knowledge, indicating the saturation of the research material.

Table 2. Details of case companies and interviewees.

Company	Field of Activity	Size of the Company	No. of Interviewees	Role of Interviewees
I	Benchmark company, electronics manufacturing	Large-sized business	6	VP, Business Development and Services Manager, Engineering and After Sales Services Head of Digital Platform Senior Manager, Master Data Management Director, Design and Test Development Director of Information Technology
II	Benchmark company, engineering, manufacturing, and service company	Large-sized business	3	Lean Operating Model Owner Enterprise Data Architect, PLM Head of Product Lifecycle Management
III	Benchmark company, engineering, manufacturing, and service company	Large-sized business	2	Manager, Product Lifecycle Process Head of Data Governance and Master Data
IV	Construction company, main contractor	Large-sized business	3	Building Systems Manager Chief Information Officer VDC and BIM Manager
V	Construction company, main contractor	Large-sized business	3	Vice President, Digital Services and Innovation Vice President, R&D IT Manager
VI	Construction company, main contractor	Large-sized business	4	Director of Investments and Risk Management Development Manager Senior Vice President, Customer Shipping and Living Services BIM Manager
VII	Construction company, main contractor	Large-sized business	2	Chief Executive Officer Director of Development and Information Management
VIII	Construction company, main contractor	Medium-sized businesses	7	Head of IT Business Analyst Development Manager Development Engineer Construction Project Manager (x2) Cost Estimation Manager
IX	Construction company, main contractor	Large-sized business	2	Developing Manager IT Manager

Purposive sampling was applied [69], allowing companies to nominate participants for focus group interviews. Interviewees with substantial knowledge and interest in industrialization were requested, and the companies provided a list of competent informants. Interviewee participation for interviews was personally volunteered, and companies were requested to assign volunteers based on their expertise on questions in the question guide. This sample size was seen as appropriate for the qualitative study as the interview questions were answered comprehensively with knowledge related to all the questions. Interviewees' perspectives on crucial but not-yet-discussed topics were also questioned. Interviewees were provided with the interview questionnaire beforehand to allow smooth discussion and the possibility to prepare for the interview. All interviews were conducted online and recorded and transcribed for data analysis.

Gioia's systematic approach [70] was applied to the analysis of the data. This rigorous analytical and conceptual technique supports the inductive approach and enhances the accuracy of data interpretation and the validity of results [70]. The first step, data coding, involves analyzing and grouping interview transcripts based on similarities in the quotes. Quotes aligned with the research objectives were extracted and coded by phrasal descriptions. In the second step, theme development, the identified groups were given phrasal descriptions to be further developed into descriptive "Areas". Based on similarities in the quotes, the "Areas" were divided into "Elements", "sub-elements", and "details", creating a hierarchical data structure. In the third, final step, the "Areas", "Elements", "sub-elements", and "details" were linked to form a coherent structure to help explain the studied phenomenon. NVivo software was used to analyze the data, following node-based thematic analysis [71], which ensured process rigor and made data management straightforward [72]. Data structures were analyzed via the Gioia method [70] and NVivo (NVivo is a qualitative data analysis software designed to help researchers organize, analyze, and derive insights from qualitative data). The findings are presented in sections covering business processes, products, and data. The overall industrialization challenges were synthesized and compared against benchmark companies. In the final phase, the empirical data, extant literature, and the parallel development of industrialization were systematically combined into steps for construction companies to improve their industrialized operations.

4. Results and Analysis

4.1. Current State in Industry

This section divides the current state (Section 4.1) and respective analysis (Section 4.2) of the benchmark companies, construction companies, and the related findings into three sections: product, process, and data. These areas (product, process, and data) of challenges and analysis were originally depicted from earlier research on manufacturing companies, and then, the benchmarks of manufacturing companies and challenges of construction companies are described. The term product refers to a tangible or intangible item offered for sale to customers, process stands for the operational business process, and data refers to data and data management processes. Each subsection begins with the benchmarks, followed by construction-related results, and concludes with a summary of the analysis with relevant comparisons to highlight areas for improvement.

4.1.1. Product-Related Challenges

Benchmark companies

Products in the benchmark companies were typically well-defined based on predefined product requirements and required KPIs. The predefined product-related details and processes provided a common overview and shared understanding of the products. The products had owners from concept to item through the product levels. Also, the apparent product lifecycle stages were mapped: time-to-market, market fulfillment (manufacturing), ramp-down, and sustaining services processes. In some cases, the product portfolios were consistently defined and structured on both technical and commercial sides as a part of the companies' well-defined PDM and PLM. However, there were some inconsistencies in describing the product portfolio due to the lack of proper product structure for some products/services.

Understanding the profitability of products was insufficient in one of the benchmark companies, which was caused by an extensively diverse portfolio, making it challenging to manage. They were aware of the problem and attempting to improve the consistency of the product portfolio and shift their focus toward profitable products.

Construction companies

The construction companies did not seem to have a common understanding of the product. Regarding physical products, some considered the entire building as a product, while others viewed the building elements as products. Some viewed projects as products. Selling and renting services were also mentioned as service types of construction products. Product requirements and KPIs were, in some cases, defined and, in other cases, only partially defined and ambiguous. Only some products had owners, and there were phase or process owners instead of product owners.

A lack of agreement on the stages of the product lifecycle was apparent, referring to delivery project phases (project planning and development, premarketing, production, and warranty) or main processes (research and project development, bidding, design, production, warranty, and care). The product portfolio was recognized and defined in some cases but mainly commercially, and the technical perspectives were poorly addressed. One of the companies claimed that the product portfolio is intentionally undefined, as products are customized and unique. The PDM and PLM processes were thoroughly defined in one case and only loosely defined or not outlined in others.

Comparing benchmark- and construction company product-related challenges

The following areas are those where the benchmark companies are advanced, but construction companies have challenges:

- Unambiguity and shared understanding of the products, product lifecycle stages, PDM/PLM, product /process owners' role and responsibilities, and product requirements, targets, and metrics;
- Clear product ownership;
- The product portfolio is streamlined and well-developed.

It was evidenced that a product is conceived as a "unique" project in construction. The product definition is very flawed and lacks agreement. Initial steps were taken toward reaping the benefits of modularity, as certain predefined elements were applied in some companies. This is a step toward modularity but is half-hearted when there is no agreement about a product as an entity. This results in the product, its lifecycle stages, requirements, and even owners not being predefined. A defined product is a prerequisite for other activities in a business value chain, which is a significant gap in construction companies. This situation results in other product-related functions, like PDM, PLM, and PPM, suffering and operating in an industrial, effective manner becoming challenging.

4.1.2. Processes-Related Challenges

Benchmark companies

The benchmark companies' processes are defined and mapped. Each process is composed of numerous sub-processes. The processes are typically divided into three categories: business, management, and support. Market-to-order, order-to-cash, and product lifecycle management are sequential sub-processes that, in conjunction with management and supporting processes, constitute the benchmark companies' major processes. Market-to-order creates products based on customer demand. This process involves collecting customer orders and translating them into a production plan. The market-to-order process ensures that products are manufactured based on actual customer demand, which reduces the need for excess inventory and helps to optimize production efficiency. Order-to-cash fulfills customer orders and receives payment. This process involves creating a sales order, packing the product, and delivering it to the customer. Once the product has been delivered, the customer pays for it, and the order is marked as complete. PLM is the process of managing a product from its inception to its retirement. This process involves several phases, including product design, prototyping, testing, and manufacturing. PLM ensures products are designed and manufactured efficiently, with minimal waste and errors. Customer-related processes are tied closely to the above processes. Management processes provide strategic planning, legal compliance, and mergers and acquisitions, all of which support and interact with other processes. Master data management and demand and development support are services that support management processes. Financial, human resources, marketing, and legal operations that complement and communicate with processes are examples of supporting processes. Certain complementary elements enrich each business process. The process model highlights how processes are linked.

The benchmark companies demonstrate advancement in the predefined processes and process requirements, as well as the process owners' well-defined roles and responsibilities at the unit and global levels. The key operational systems are mainly linked to the processes. Their systems have clear roles: a PLM system is used to manage product data throughout the product lifecycle, a PPM system is used to manage the product portfolio, ERP manages delivery and maintenance data, and CRM manages sales processes and customer data. The finance and service system supports PayPal and netting services and spare parts pricing, for example. Performance management systems evaluate each process's performance against KPIs and identify areas for improvement. Moreover, a governance model aids standardization and ensures the implications of all these elements within the processes.

The findings indicate that the integration between processes and IT systems varies. In cases where the description of IT systems, relevant data, and roles are predefined, their interaction within the business process is well harmonized. In some processes, strict integration exists between the process and the IT system, and the workflow is directly impacted or controlled by the IT system. However, some processes are not directly connected, but the process and the IT system are in parallel. Master data are indicated as a connector of the integrated processes, and for those partially connected, the process owner plays a crucial role in ensuring data consistency based on predefined KPIs and requirements. Another challenge is the negative side of a high level of integration. Making changes in heavily linked IT systems and processes is a complex and time-consuming task, hindering the realization of necessary improvements.

Construction companies

In construction companies, the key processes are usually divided into two broad categories: construction processes and other processes. The construction processes start with research and project development and continue with bidding, production, warranty, and care processes. Other processes include sales and marketing, operational development, and support processes. Each of these processes is composed of numerous sub-processes.

Regarding process ownership, there was ambiguity about who is the owner of which process. The interviewee statements also vary in those cases where there are process owners, with some seeing individuals owning the processes and others, a core group of individuals (such as board members). In some cases, there were phase owners (the construction phase) instead of process owners.

Regarding the operational systems in use, it was found that various IT systems (BIM, CAD, CRM, PLM, cost management, etc.) are not fully integrated with the processes. There are indications that the highest integration among IT systems and processes is in the design and computing processes. Manual data transition takes place in other processes. IT systems, such as BIM and PLM, are not part of the companies' operations; these systems are mostly used for viewing the building plans and for limited managerial purposes. Consequently, there is no complete application of BIM, PDM, PLM, or ERP in the studied construction companies.

Comparing benchmark- and construction company process-related challenges

The following areas are those where the benchmark companies succeed but construction companies have challenges:

- Uniform and defined processes;
- Unambiguity regarding business process ownership;
- Integration and efficient use of IT systems.

In construction companies, there was ambiguity around processes and their requirements. Some processes had owners, and some did not, and there was vagueness in the process owner roles. Process or phase owners with a project-by-project variation were identified. Integrating IT systems and processes was mainly realized in design and computing processes, and other processes were not concerted via interoperable IT systems. Processes varying project by project caused challenges in perceiving process requirements. When a business process exists, a process owner does not have a clear view of the process requirements and their roles and responsibilities in managing the process. Similarly, ambiguous and random data might be hindering the processes' linkage with IT systems.

4.1.3. Data-Related Challenges

Benchmark companies

The findings from the benchmark companies show that typically two types of data were created in processes: master data that defines the business process object in question (definitive) and transactional data. Examples of definitive data are product and item master data, customer master data, vendor master data, and agreement master data. Service data, sales order data, and purchase order data are examples of transactional data mentioned by the benchmark companies. In addition, there were two types of data in use: core data that are commonly used by different processes, and data that are not defined, but quality solutions monitor their consistency throughout the processes. The data were systematically stored locally and in the cloud in business IT tools.

There were well-defined processes for product data, starting with core data creation in PLM, which was common for all processes and consisted of roughly ten attributes. The data owner extends the core data into Item master data, which have 40–50 attributes. The data owner also defines the KPIs, data quality rules, and procedures. The item master data are marked as sellable items on SAP for E-commerce. Data quality solutions monitor and control the quality and consistency of master data across several IT systems.

Data ownership was typically clearly defined, depending on the processes owned by PLM, the product owner, or the process owner. Regarding data strategy, guidelines are developed for PDM, indicating how data were created, enriched, utilized, and maintained. One of the cases used a matrix of master data and processes to highlight their intersections, analyze business and data process contact points, and act based on predefined expectations.

The benchmark companies recognized the importance of an officially defined data strategy for effective product data management. While a data strategy did not currently exist in the benchmark companies, it was actively being developed to avoid the unnecessary data spread that currently occurs in the benchmark companies. They also saw the potential for advancement in the significant amount of unused data, particularly data from services and consumer feedback that were not systematically looped back into product development. A data hub in which data are collected and analyzed to support decision-making was yet to be realized but was being developed.

Construction companies

The variety of data types generated in the processes of construction projects was wide. There was no formal categorization of data types in projects, and data types varied depending on the domain where data were created, including project development, construction and operation, customer, financial, supplier, and personnel domains. Some of these data were definitive, such as product master data, project location master data, customer master data, supplier data, and financial data. It was evident that the value of definitive data were perceived in some areas; however, there was still no clear understanding of definitive data among the studied construction cases.

The companies had different viewpoints about which processes use which data, but it was commonly agreed that many processes depend on information from one to another. One company mentioned that data transferred between processes could be divided into three segments: data for accounting, construction sites, and the IoT. Accounting receives data from the IoT tools that convey financial details for accounting. Scheduling is essential regarding production; this sector could be improved further to improve construction site situational awareness. The IoT communicates environmental data to enhance situational awareness, for example, regarding the realization of optimal drying and hardening for concrete structures. Another company noted how data coming from the design and work site phases were used by different actors, warranty service departments, etc. However, there was much room for improvement to achieve a common understanding of data processes.

The construction companies suffered from disintegrated data and information systems. Only one of the cases indicated that data were stored in a data hub that acts as centralized information storage. This evidences the feasibility of applying data hubs in construction projects. The companies had difficulties following where the latest, updated data were located, as data were stored in multiple silos: the cloud, network drive, and even employees' computers. One of the companies had over 100 information systems in use, making their integration rather challenging. In addition, information sharing via documents, such as Excel tables, takes place. Another raised concerns over manual data entry, which is prone to errors as there is no automation.

Product data processes were not defined, but one logic existed: the next phase uses data created in the earlier phases. According to one company, data were flowing as needed, and there was no predefined holistic data flow strategy. There was high ambiguity regarding the process and product data owners. The process/phase owner owns the data, and as the process changes, the responsibilities of the process owner pass to the next process owner. Regarding product data ownership, only one company indicated that this role exists at item owner and concept owner levels. Other cases stated that the process owner or other project staff are considered product data owners.

Comparing benchmark- and construction company data-related challenges

The following areas are those where the benchmark companies are advanced, but the construction companies have challenges:

- Integrated processes create connected data;
- Data are stored in a manner that is available for all;
- The role of definitive data is recognized and has a predefined structure;
- There is unambiguity and understanding of data utilization processes and data ownership;
- Product data processes are defined, and data flow is based on product and process requirements;
- Data strategy exists;
- Process modeling for data.

According to the findings, the value of data seems to be somewhat recognized but not realized in the construction companies. The discussed product- and process-related challenges impact the realization of the data value in construction. Connected data are possible to be created and used in integrated processes. Should there be no defined data strategies and if the data flow is as needed, the value of the data cannot be captured. Should the product, its requirements, and the target market not be predefined, ambiguity in product data processes is inevitable.

4.2. Analysis of Industrialization Challenges

Table 3 summarizes data regarding the status of industrialization elements in the benchmark and construction companies. As a result of the comparison, the industrialization challenges in construction companies were drawn.

In the benchmark companies, processes, products, and data are appropriately integrated and harmonized. This harmonization is made possible by predefined targets and metrics. Regarding products, a shared understanding of products or services, sales, and maintenance for a particular customer is observed. Also, the companies' products are well-defined based on requirements (product and customer) and KPIs. Moreover, in between, there are well-governed data.

Table 3. Industrialization challenges in construction companies compared to industrialization status in manufacturing companies.

	Findings in Benchmark (Manufacturing) Companies	Findings in Construction Companies	Industrialization Challenges in Construction Companies
Product	• Defined (physical/digital and services) • Defined and clear product lifecycle • PPM is inconsistent in some cases (commercially and technically) • PLM • Defined product requirements and KPIs • Partially defined customer requirements • Product owners with clear roles and responsibilities	• Diversity and ambiguity in product identity (whole building, whole project, elements of building as a product and services) • Product lifecycle stages differ project by project and are not defined • PPM intentionally left undefined (if exists, mainly commercial) • Partially used PLM • Only some products have owners (process and phase owners instead of product owners)	• Lack of shared understanding of processes • Incompatible IT systems and processes • Lack of shared understanding of the product itself, its requirements, and KPIs • Ambiguity in product lifecycle stages • Insufficient use of PDM/PLM • Insufficient PPM • Disintegrated processes create disconnected data • Data are stored in info silos • Some data are definitive and have a predefined structure • Product data processes are not transparent, and data do not flow as needed • Ambiguity in data utilization processes and data ownership • Lack of data strategy • Insufficiencies in process, product, and data ownership
Process	• Defined and modeled processes • Mostly integrated with IT tools • Some problems in IT system integration • Process owners with clear roles and responsibilities	• Lack of shared understanding of processes • Processes are not modeled • Ambiguity about the role of process owners and their responsibilities	
Data	• Definitive and transactional data • Product data processes are transparent and defined • Product data have an owner • Data flow based on product and process requirements • Data strategy is used but still not a single formal data strategy • Data stored in connected IT systems, data hub under development	• Some of the data are definitive and structured • Data stored in disconnected info silos • Data utilization processes and data ownership are not transparent • Data strategy does not exist • Data stored in numerous disconnected IT systems, data hub exists in one of cases	

Certain industrialization challenges in construction companies seem to prevent the above-mentioned. If compared to the benchmark companies' status in industrialization, lower levels of defined products, processes, and data can be observed in the construction companies. The products are mainly conceived as unique and are poorly defined, hindering repetitive production that requires different arrangements in processes. Consequently, it appears challenging for the construction companies to predefine the business processes, resulting in ambiguities. The ambiguities in products and processes make the information flow challenging, even though advanced tools are being used.

4.3. Developing the Steps of Industrialization

The steps for industrialization are the novel contribution of this paper, especially the logical order of items created. These steps are summarized into individual recommendations below. Figure 2 describes the fundamentals of project-based construction to transfer to industrialized businesses from the analyzed comparison and supported with relevant earlier research. The steps in Figure 2 are created based on earlier research findings (partially presented in Section 2) and the analysis of industrialization challenges in construction companies compared to the industrialization status in manufacturing companies.

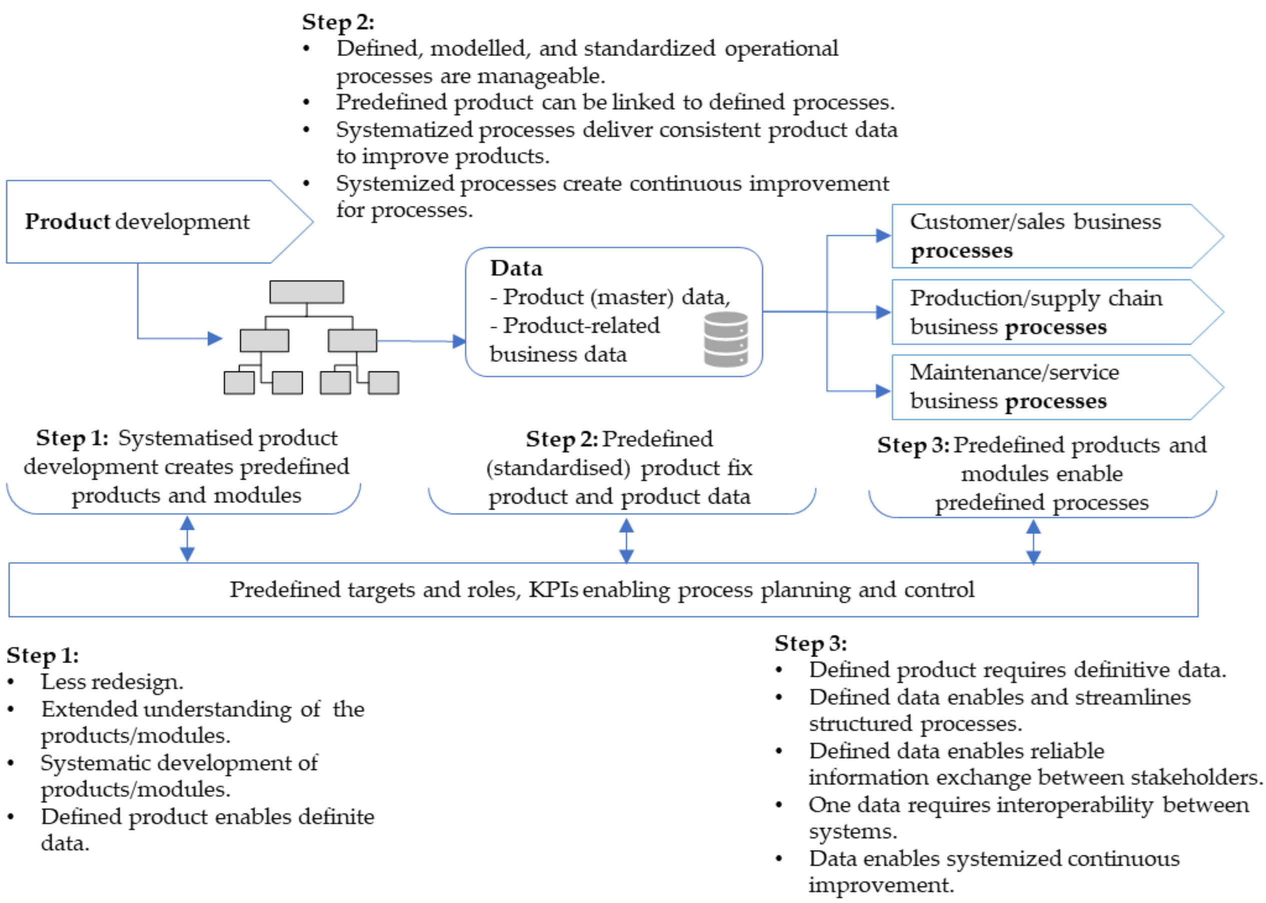

Figure 2. Focus and key steps while working toward intensifying industrial operation in construction. Systematics to benefit industrialization and efficiency improvement.

Product, process, and respective data on both are identified as key elements of industrialization. Naturally, the nature of construction businesses requires a certain amount of project-specific elements and uniqueness. In construction processes (the implementation of projects), costs accumulate during implementation. However, processes cannot operate without data, no matter the level of project specificity. In the manufacturing industry, even the engineer-to-order production mode is initiated with product-specific data as opposed to in construction, where implementation typically begins with imperfect data or data changes during the process.

There are also a significant number of studies that support the use of module-based solutions in product specification [40–42]. Undeniably, there will be configurability and some personalization and uniqueness, but with sufficiently predefined product elements, it is possible to get close to a predefined offering. Even at the element level, a predefined product will considerably reduce rework for redesigning products in construction projects. Product structure is an approach that is the backbone of a predefined product, allowing a streamlined portfolio and the transparent lifecycle stages of the product. As expected, it is shown that a predefined product facilitates a shared understanding of the product itself, its requirements, targets, metrics, and product lifecycle stages.

Recommendation 1: Increasing the level of predefined elements and modules increases the efficiency of the process. In the case of a configurable or personalized building, product specification still needs to be defined for implementation.

The starting point for industrialized operations is the product. This underlines how crucial a predefined product is. From a well-defined product, product-related data can be derived to be used in business processes (sub-processes, like production planning, scheduling, sourcing logistics, etc. (see, e.g., [73]). In the product development process, data are released to be used in other business processes. Indeed, for a defined product, the data should be definitive (master data) and structured based on the business objectives that are agreed on and shared across the business processes [74]. Product data need to be defined concerning configurable and project-wise case-specific elements. Product data are often stored in PDM/PLM systems (product data management/product life-cycle management) to ensure flow through the lifecycle. This is possible with transparent and defined product data processes. Construction aims to utilize BIM for the same purpose, but the maturity is very far from what manufacturing uses. Consequently, product data cannot be defined if the product is not well defined, resulting in ambiguity in product data processes.

With predefined product data, the process of data creation, storage, and usage will become transparent. This confirms previous findings in the literature that a predefined standardized product structure as an information repository is the missing linkage between the disconnected construction processes and information systems [52,53]. These results extend our knowledge of facilitating data management in construction companies as a step toward applying a data strategy and data hub.

In addition to definitive product data, the product-related business data and process data created in business processes need to be maintained to enable consistent data across the project [75]. Indeed, data obtained from predefined products and processes can flow from a product to processes and vice versa via different connected IT systems. Once the product is clearly defined and the data are available, business processes can benefit from achieving economies of scale via systemized repetition in products and processes [52]. With modular and repeatable product architecture, industrialization is also supported [38]. Even though the configurable product greatly affects the cost of building, the cost of building is accumulated in products and processes. Indeed, if the predefined systematization of a process that utilizes consistent product data exists, extensive savings in the production process could be achieved.

Recommendation 2: Product and business process data need to be predefined to enable well-planned operations and implementation. Changing and volatile data cause variability in all the following processes, causing individualized and inconsistent activities in the processes, and finally resulting in inefficiency and impossibility for continuous improvements.

Operational business processes vary by company, but the main processes in all manufacturing company cases involve customer/sales, production/supply chain, and maintenance/service. The business processes need to be defined based on products and data. It is important to note that defining processes enables the use of several smaller processes rather than one large one (e.g., construction processes in construction), allowing for parallel processing and being more resilient and flexible. If these processes and their objectives are defined, the integration of business processes is being facilitated. Further, integrated business processes create integrated data. In addition to product data, business processes create customer/sales, production, supply chain, maintenance, and service data, referred to as product-related business data [74]. Regardless of the product- or product-related business data, the data can link the product development process (predefined parts of the building and case-specifically configured) and other business processes (construction and its sub-processes) [73]. This linkage enables addressing challenges in the integration of data and IT systems. Here, the critical role of product-, data-, and process owners cannot be underestimated. The definitive data enable the integration of the connected IT systems and business processes. We propose that where systems cannot be connected, the product-, data-, and process owners collaboratively play a decisive role in the connection and flow of information between systems and business processes.

Recommendation 3: The operational business processes must be efficiently planned, organized, led, and controlled through the defined product, e.g., construction and its sub-processes. The systematization of processes enables pre-planning and improved cost, quality, and time control, and finally results in efficiency improvements.

Finally, predefined targets and metrics containing product and process requirements, product, data- and process owners' roles and responsibilities, and a data strategy play a crucial role in supporting the consistency of work, data flow, and the successful implementation of industrialization. This strengthens the argument made earlier about the crucial role that CI plays in the industrialization of the construction industry since recurring processes allow for the reuse of metrics and expertise [2].

5. Conclusions

The key contribution of this study is in the elements and more specific descriptions and reasoning of the industrialization of the construction industry. Research on the repetitive manufacturing industry has described the importance of processes, predefined offerings (products), and the respective data, among other elements, securing efficiency in their internal operations. In this study, we highlight the logical order and connections of these elements in the industrialization of construction.

The comparative empirical data from manufacturing companies give evidence that the industrial operational model can be implemented in configure-to-order, design-to-order, or even engineer-to-order modes. The logic applied in these analyzed comparative companies proves that this could be achieved in construction if willing to industrialize, increase efficiency, and finally increase productivity. In construction companies, this requires a change in the mindset and an effort to end the project-specific mindset and prototype production logic.

Disengaging from project specificity means firstly increasing the level of predefined elements and modules in the product (building). In addition, there needs to be fundamental discipline in defining the product early and not leaving the product specification floating, and then, all the following processes will share the same and correct data. Secondly, defined specific and stable product data enable systematization: the planning, organizing, leading, and controlling of processes or sub-processes. Thirdly, systematic process management enables efficiency improvements in industrialized set-ups.

This logic is fully in line with what the automotive industry has implemented with Lean [16], with the linking element of data and information management. This study adds value to the findings by Jansson et al. [1] by emphasizing how prefabrication or the application of modularity is not enough for industrialization if the product as an entity is not defined and the operations are more ad hoc, unique projects. The findings provide support for Brege et al. [18] in understanding that the level of industrialization affects the level and nature of project-specific work and relates to the level of predefinition related to the products. This research provides the construction industry with a reference point to evaluate future opportunities and directions for industrialized construction.

Despite making an empirical contribution, there are undoubtedly some limits to our study. Firstly, a limited number of companies are considered, which may affect the generalizability of the findings. Also, while we included a mix of benchmark companies from manufacturing and companies from construction to provide context and compare the challenges, a larger sample for both qualitative and quantitative research may be necessary to fully establish the applicability of the findings and their validity. Furthermore, the applied qualitative approach may introduce bias or subjectivity in the data analysis. Finally, further work is needed to confirm the effectiveness of the proposed steps to improve industrialization in construction, as they can be seen as rather high-level and conceptual. It is important to note that the context of each organization may vary, and what works for one may not work for another.

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Appendix A

Interview Questionnaire
Product
What are the products of your company?
What is the primary source of income in your business?
Do you have a consistent, structured way to describe your product portfolio?
Commercially? Please describe.
Technically? Please describe.
Have you defined product lifecycle stages? If yes, please name them.
Do you have a defined product management/product lifecycle management process?
Do products have owners?
Do you have well-defined product requirements, guidelines, targets, and metrics?
Processes
What are the main business processes of your company?—please name them.
Do processes and sub-processes have owners?
Which operational systems/tools do you utilize –PLM/ PDM, CAD/CAE, ERP, other?
How do the IT systems integrate business processes?
Do the IT systems link to the named business processes?
Data
What type of data are created by each of the business processes?
Which of these data are definitive by nature? Please provide examples. Please go through the named business processes one by one.
Where are these data stored?
Do you know which business processes use that data and how/what for?
What data do you receive from other business processes? Where do you get these data from?
Are there any data you would need from other business processes but are not receiving at the moment? Do you know why you are not getting it at the moment?
What data are owned by each business process?
What are the main processes for product data?
Has the company organized product data ownership, and if so, how?
Do you have a defined data strategy? If yes, what is it like?
Does the company have a data hub to collect and analyze the data for business decisions?
What are the main challenges in data creation, utilization and quality in different business processes?

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