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DesignChain: Process Automation From Recording Of Customer Requirements To Production Release

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Abstract

Growing price pressure due to an increasing number of global suppliers, increasing individualization of products and ever-shorter development cycles are challenges facing the engineering industry. In this context, mass personalization represents the customized production of customer products with batch size one at the low unit costs of mass production.

The possibilities of digitalization and automation of technical order processing open up the opportunity for companies to significantly reduce their complexity costs and lead times and thus increase their competitiveness. Many companies already use a range of simulation tools and configuration solutions but only as stand-alones. Often, the expert knowledge of employees is hidden in "knowledge silos" and is rarely networked across processes.

The concept "DesignChain" will address these challenges by automating and digitalizing technical process planning from recording customer requirements to releasing a product to the shop floor. Configurators within DesignChain allow for mapping variant-rich products. This transformation of customer requirements into product properties makes it possible to generate even complex CAD models, such as models for large-scale equipment based on specific rules. An automated CAx chain will help to digitally transfer production-relevant documents to the shop floor for parts fabrication. This process, which can be fully automated, allows for the customized creation of variants based on current approval statuses.

Keywords

DesignChain; mass personalization; configurator; CAD; automation; CAx; process chain; CAM; technical process planning, digitalization

1. Introduction

The advent of modern technology and changing consumer preferences have led to an increased demand for personalized products. Customers now seek products that reflect their unique tastes, preferences, and requirements. Nowadays, companies have to keep the balance between offering products tailored to customer needs and manufacturing products quickly and cost-effectively. Achieving these goals poses a challenge to production as such and to the preparation of production – especially in technical process planning. Manual activities in indirect areas of the order processing chain lead to long lead times and high costs for customized products [1]. Employees across departments and functions spend a large proportion of their working day searching for the right information. This is mainly due to the insufficient coordination of cross-departmental processes. This paper explores what role a DesignChain can play in the technical order processing of customized products. It examines how the successful integration of DesignChain can enhance the efficiency of order processing and customization ultimately lead to improved customer satisfaction.

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1.1 Initial situation

The procedure for processing orders is heavily dependent on robust technical process planning, which includes designing individual variants, creating bills of material, as well as numerical control (NC) programs for machine tools. These are manual tasks that can hardly be tailored to batch size one. This means that, if the case arises, separate individual designs, parts lists and NC codes must be created for each variant. In the toolmaking industry, for instance, the continuing automation of production brings about that more employees are distributed to processes carried out in upstream production stages [2]. At the same time, 29% of design work is outsourced due to a lack of capacity [2]. This means that production preparation requires more and more time while the necessary specialized staff is missing or not available in sufficient numbers. This leads to the following problem statement:

How can the production preparation effort be reduced as the degree of customization continues to increase?

1.2 Possible solutions

Solutions are already available that use digitalization and automation tools for addressing the challenge of skilled workers shortage in production preparation:

1) (Product) configurators for translating customer requirements into technical specifications [3]; [4],

2) Automation of CAD programs for rule-based modification of designs [5], and

3) Computer-aided manufacturing (CAM) programs for simulating machining operations and the associated derivation of NC programs [6].

The process chain is typically not end-to-end and, thus, the IT landscape is very heterogeneous.

2. State of the art

2.1 Mass Personalization

The proliferation of e-commerce platforms and advancements in manufacturing technologies provides better access for customers to unique and customizable products. From clothing and accessories to home decor and electronics, personalized options are becoming increasingly prevalent across various industries. Customization allows customers to feel a sense of ownership and connection with their products. It enables businesses to create a unique selling proposition, differentiate themselves from competitors, and foster stronger customer loyalty. As a result, companies must adapt their operations to meet the demands of individualization effectively. This trend can be observed both in the end customer segment, and in the business-to-business (B2B) segment. Even complex industrial goods are increasingly required to adapt to the customer's individual circumstances.

Accordingly, mass personalization calls for a paradigm shift from "production to stock" to "production to order" [7]. This paradigm shift must be accomplished in the order processing chain, which will be discussed in the following paragraph.

2.2 Order processing

Order processing refers to the process of managing customer orders, from order lead to delivery of the product or service to the customer (lead to cash) [8]. Thus, order processing is a typical end-to-end process. It includes planning, monitoring, and controlling orders to ensure they are completed on time and within budget. Order processing also involves communication with customers, coordination of suppliers, and management of contracts and financial aspects. The typical handling of a customer order covers three process phases: Clarification and release, procurement and production, and shipment and completion [8]. In a commercial environment where personalization plays a major role, make-to-stock processing is rarely applicable. Products and/or semi-finished products cannot be kept in stock for specific individualization. These use cases often require to provide a certain amount of technical functions in the order processing.

The Y-CIM model according to Scheer illustrates how logistical and technical tasks in a production company interact [9]. The model seeks to represent functions in the order of sequence, indicating details down to the level of data and function model [9]. It thus provides a framework for the systems used and how they are connected. The left branch consists of the logistic tasks for production planning and control. The right branch points out the typical engineering process chain. The model assumes that the planning and implementation phase only begins after the design phase.

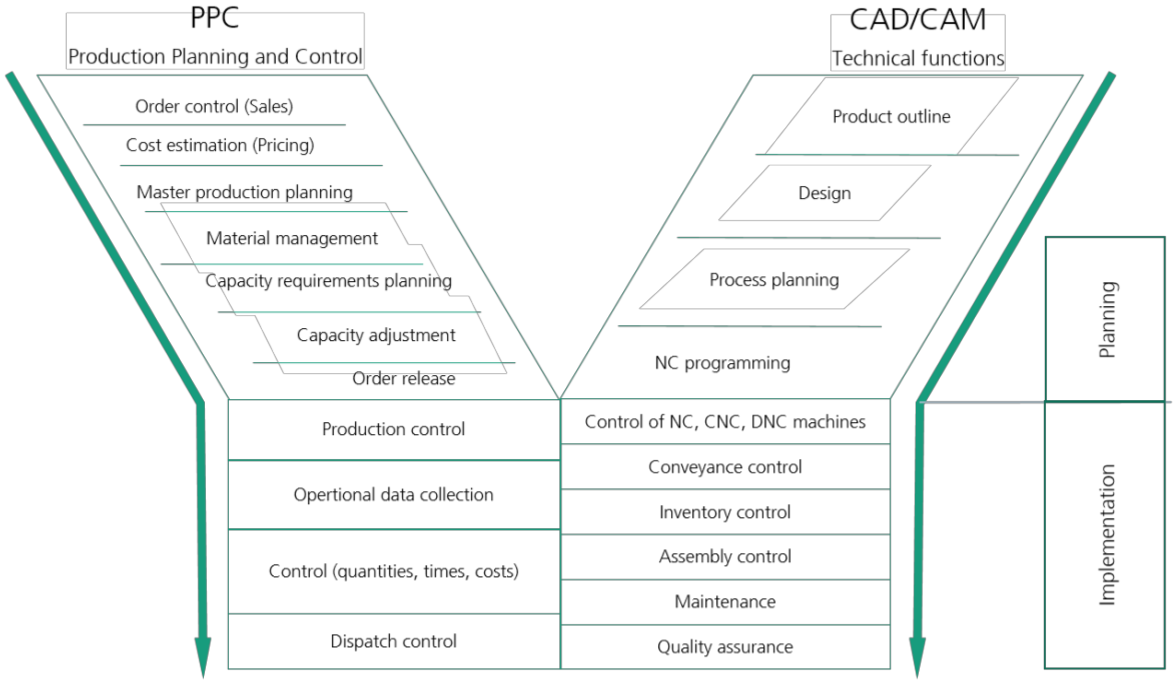

Figure 1: Information system in production, in accordance with [9]

So far, product configurator software has primarily been utilized as commercial sales configurators within order processing systems [10]. These configurators effectively handle products composed solely of pre-designed components. However, certain products require a combination of pre-designed, parametric, and customizable elements, such as specialty valves used in the process industry. In such cases, the engineering phase necessitates support both from a configurator and from other applications, such as CAD/CAM/CAE tools to ensure the seamless creation of a fully functional end product. Since these software depend heavily on user input, which in turn depends heavily on the business context, they are mainly operated by humans.

2.3 Technical process planning

The current state of the art in technical process planning for manufacturing preparation is to use 3D modelling and simulation-based planning software [11]. These methods allow processes to be virtually tested and optimized before being implemented in production. This can lead to greater efficiency, lower costs and shorter time to market or time to customer.

State of the art in supporting the technical process planning of order processing are computer-aided software. The goal is to improve process efficiency and accuracy by automating manual tasks. The technologies and methods mainly used in work preparation include [12]:

CAD (Computer-Aided Design): CAD software is used to create digital models of products. These models are used to create a virtual production environment in which production processes can be simulated and optimized. (E.g.: Autodesk Inventor, Dassault Systèmes SolidWorks, Siemens NX and many more)

CAM (Computer-Aided Manufacturing): CAM software is used to plan and control production processes. The software automatically generates work instructions and machine programs that control the production process. (E.g.: HCL Technologies CAMWorks, Dassault Systèmes SolidWorks CAM, Mastercam and many more)

PDM (Product Data Management) software manages and organizes production data. It provides a central source for storing and managing information about the product, including design data, bills of materials, work instructions, and manufacturing processes. (E.g.: Autodesk Vault, Siemens Teamcenter, Parametric Technology GmbH Windchill and many more)

ERP (Enterprise Resource Planning) software collects and integrates data from different business areas such as production, purchasing, sales and finance. These software enable seamless communication and coordination between the different departments. In the technical context they are mainly used for managing and/or creating work plans. (E.g.: SAP, Microsoft Dynamics NAV, Infor, proALPHA and many more)

Further developments in the field of technical process planning for manufacturing preparation include the integration of artificial intelligence (AI) and machine learning [15]. These technologies enable processes to be predicted and optimized even more accurately. In addition, AI systems can make decisions on their own and automatically adjust processes to achieve optimal results. Current research in this field is mainly related to deriving workflow sequences and work plans.

The general state of the art in technical process planning enables greater efficiency, flexibility and quality in manufacturing preparation. Using 3D modelling, simulation-based planning, advanced software solutions and AI enables companies to respond quickly to changes in the market and remain competitive.

3. Definition and components of the DesignChain

DesignChain describes a digital, automated and seamless technical end-to-end process chain from the recording of customer requirements to the handover to the shop floor. In its final stage of maturity, it will fully autonomously convert technical customer requirements into the relevant information of the product needed for production – still, it is currently more of a vision than a feasible solution. However, similar to the various levels of automating the driving functions in automobiles, DesignChain can already offer benefits even at lower levels of autonomy.

Current implementation ranges from systematically recording customer requirements using company-specific workflows to transferring a validated NC code to production. The focus lies on methodically organizing and controlling features, addressing gaps in the CAx chain, and discovering potential opportunities for cost savings [16]. In the Y-CIM model, DesignChain is intended to bring the upper "branches" of the Y closer together. Like a zipper pulled from the bottom to the top, the branches can be mutually integrated. In addition, DesignChain further extends the Y-CIM model. In the Y-CIM model, the perspective of automation and end-to-end integration is only considered to a limited extent. Looking at typical CIM process chains in companies today, it appears that only few of them are automated. Accordingly, continuous automation of process execution, availability of information and provision of information is not given. Thus the term “DesignChain” is used if there is a need for continuous automation of technical process planning.

DesignChain consists of five major building blocks:

1) Product configuration: Query and transfer of individual technical customer requirements into technical parameters and interpretation of the corresponding product structure according to customer requirements. Current implementations (e.g. Configure-Price-Quote-Software (CPQ)) focus on quick quoting and lack integration into product design. As a result, the scope of variants is limited, since the focus is clearly on customer guidance.
2) Quotation costing: In most cases, relevant information for the quotation process can already be derived from the customer configuration. If this is insufficient, the following modules, e.g., automated model construction, can add further detail. This process step provides an interface to the activities of business order processing. Currently, rigid cost rates are usually used, which estimate the cost of producing the component in advance for example on the basis of the volume or surface area.
3) Automated model construction: The technical planning and derivation of machine paths or even manual assembly processes, requires the creation of a 3D CAD model. With the set of rules for the company's product portfolio, these models can be built up in the CAD software based on rules and adapted to the customer-specific configuration derived in process step one [13]. These implementations still lack an end-to-end integration into the business aspects of a company. They require a high degree of human control and, by automating the technical task, are also bound by the rules established in the implementation.
4) Automated preparation of manufacturing information: The information relevant to manufacturing is derived from the 3D model, for example, the generation of an NC code. However, the 3D model can also be enriched with further information such as measuring points for an automated on-machine inspection [14]. Current implementations, with the help of feature and macro technologies, allow programming know-how to be saved for reuse or later application. This requires a predetermination of the manufacturing features already in the design, so that the CAM software can interpret them via standardized product and manufacturing information embedded in the 3D-model.
5) Process control: A higher-level process control system helps to connect, the individual systems in a chain. Depending on the company's internal requirements, this allows for considering the established process sequences. Optimal process sequences for the display of additional interfaces or output formats, e.g., for a sales-optimized 3D model, can also be integrated into the process chain. In addition to the automated model construction, the highest degree of individualization in DesignChain can be found in setting up process control. Furthermore, the process control is responsible for facilitating the information exchange through for instance XML- (Extensible Markup Language) or JSON-files (JavaScript Object Notation) and save them temporarily for further use (for example by the CAD-System) or save them long-term in the database (PDM). Current implementations of process control mainly focus on business processes. An extension to technical processes therefore means dealing with technical parameters and information.

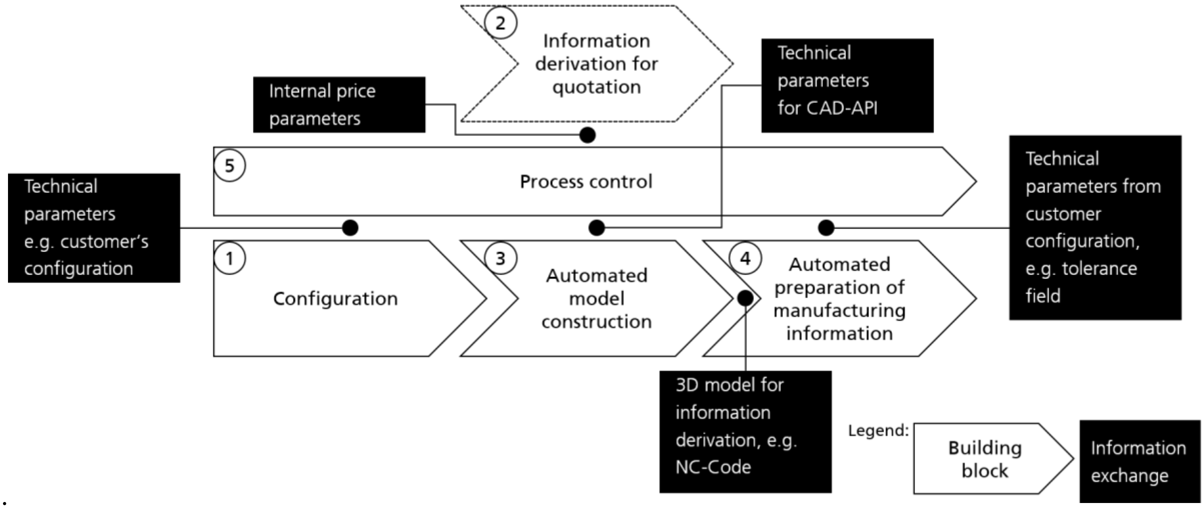

Figure 2: Building blocks of the DesignChain

4. Practical application

The first use cases in the industry are already showing promising results. As an example, with the help of DesignChain, the effort required for model creation in design in the construction industry could be significantly reduced. Now, individual assemblies are generated within a few minutes. With a user from the toolmaking industry, it was possible to build up a vision like the one shown in Figure 3. The area outlined in Green thus sets the limits for the scope of DesignChain and shows the interfaces from the company context. This means that steps one to three are within scope, and steps four to seven indicate possible interfaces to DesignChain. Step four represents the automated production of parts already designed and planned in DesignChain. The fifth step points out data acquisition on the shop floor. The data collected there can be used, for example to better coordinate order processing but also to offer added value to the customer, for instance through capacity-checked delivery dates. Step six, packaging and logistics, and step seven, the product delivery, complete the end-to-end customer-to-customer process.

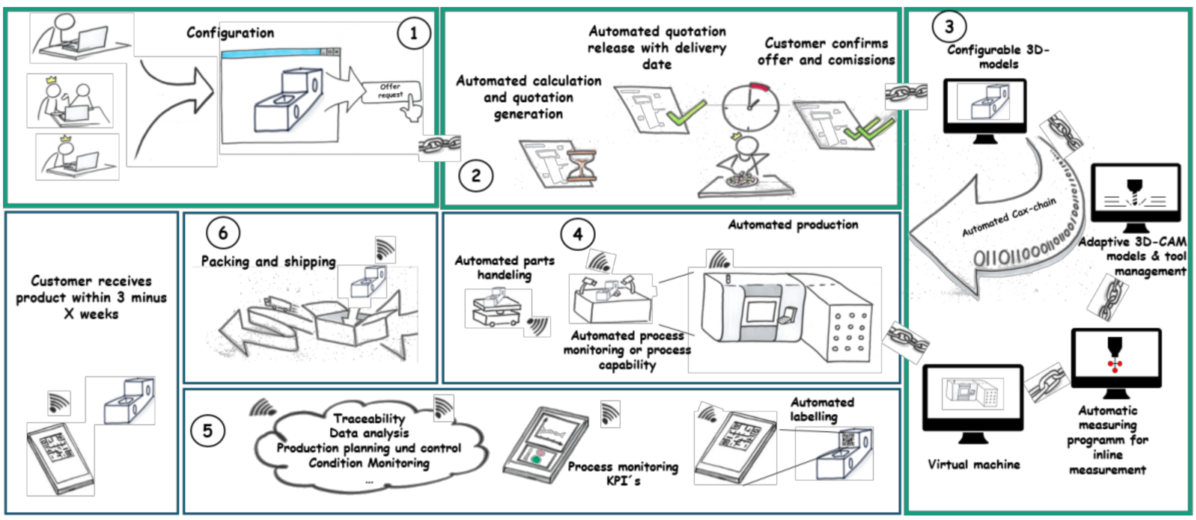

Figure 3: Implementation of an end-to-end process based on the example of Design-to-Order aimed at automating order processing [16]

In order to implement such a vision suitably into the corporate context, it is necessary to integrate the existing IT systems. The typical process chain of DesignChain utilizes the existing software in the company for technical process planning: CAD (2), CAM (3), PDM (4) and ERP (5). This process chain can be exemplified on a job shop for milled parts. First, customers enter their specific requirements for the desired milled part in the customer configurator (1). Assuming that the contract manufacturer does not accept externally created 3D models, customer requirements must be translated into technical parameters. As an example, the desired surface finish in conjunction with materiality may require specific cutting parameters. These technical parameters and customer requirements are stored in the PDM (4) with clear reference to the customer order. In the next step, the 3D model construction starts. The parameters are used to control the CAD (2) software, based on rules. The 3D model can be enriched using customer parameters, e.g., a tolerance class. The 3D model is then saved in the PDM (4) software and a bill of material (BOM) is derived. Then, the BOM can be transferred to the ERP (5) software via interface. To get the necessary information on the shop floor (6), machine paths and tools, for example are derived in the CAM (3) software. For this purpose, the 3D model is simulated in the CAM (3) software and enriched, for instance with the tool information from the ERP (5) software. Thus, at the end of the process chain, all information is available for production release and for manufacturing the product in the machine tool.

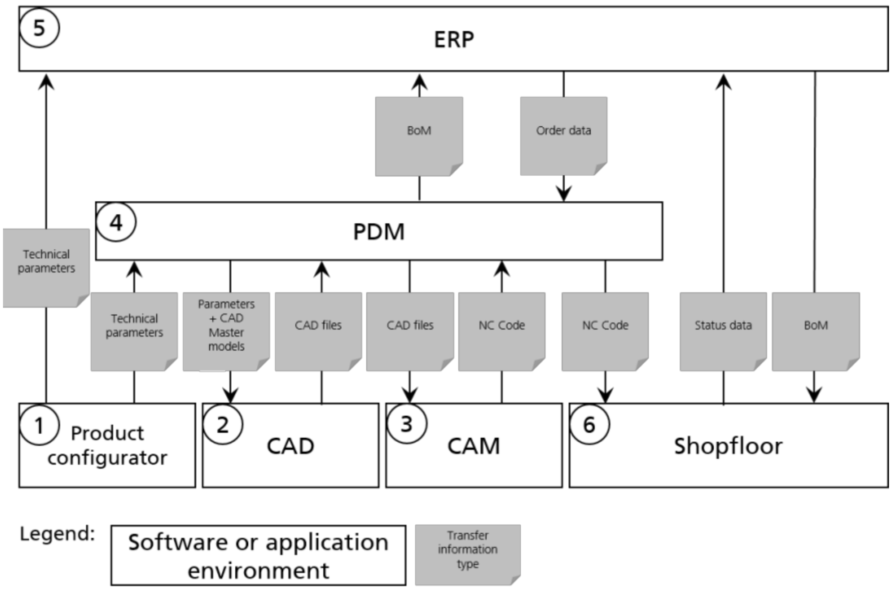

Figure 4: Typical IT-landscape in which DesignChain can be set up

With DesignChain, the functional areas are better linked, gaps in the CAx chain are closed, and potential cost savings are transparently displayed. Advantages of an implemented DesignChain include (1.) shorter throughput times, (2.) reduced effort, also in the indirect departments of the company (3) optimized information flow and (4) flawlessness of information generation. For a deeper understanding, the following paragraph elaborates on the benefits of DesignChain.

5. Key benefits of the DesignChain

By integrating DesignChain into their production, companies can streamline order processing and production processes. By consequently leveraging existing technologies such as computer-aided design (CAD), computer-aided manufacturing (CAM), and enterprise resource planning (ERP) software, businesses can efficiently manage customization requests, optimize production schedules, and reduce lead times. The benefits of DesignChain, are elaborated below:

1) DesignChain caters to individual customer needs and fosters higher levels of customer satisfaction. By offering personalized products, businesses can meet specific customer needs and preferences. Satisfied customers are more likely to become loyal brand advocates, leading to increased customer retention, positive word-of-mouth, and long-term business success.

2) DesignChain enables faster production throughput times, thereby improving the efficiency of order processing of customized products. As both technical process planning and design departments use DesignChain to derive information automatically, they move closer together, eliminating lengthy information searches.
3) DesignChain enables the potential for human error to be avoided in the provision of information through digital and automatic process flow. This ensures error-free information generation and transfer, even in hectic project business or when processing large amounts of data.
4) DesignChain automates recurring, previously manual processes in production preparation and thus relieves employees of recurring manual tasks. This enables information provision and derivation of variants with batch size one.
5) DesignChain uses the systems available in a company (CAD, CAM, PDM, etc.) to get started with automation and end-to-end consistency. This means these systems are still open for manual operations, and Engineer-to-Order (ETO) development processes can be performed in parallel and the product portfolio is further developed.

As elaborated above a potential user group that benefits most is the design department in a company. Recurring tasks customizing a product design can be adopted by the system and executed without errors. The error-free nature of the system also plays a major role for the work preparation personnel, who are also key users.

6. Discussion

Implementing DesignChain involves overcoming various challenges, such as managing a diverse range of customer preferences, ensuring the scalability of production processes, and coordinating multiple stakeholders effectively. Businesses must invest in robust systems, technologies, and training to address these challenges and seize the opportunities presented by customization. Especially in small and medium enterprises it is challenging to implement the necessary IT landscape. The development of DesignChain is also associated with a comparatively high initial effort. These frontloaded tasks consist of developing a set of rules, automating the individual systems and establishing integration - in the sense of a digitalized, automated end-to-end process. It remains to be seen how this initialization can be structured best and how, with the establishment of a digital and automated chain, a simple product structure can be created. So it is evident that DesignChain can offer a particularly large benefit when as many variants as possible run through DesignChain in order to offset the initial effort. In addition, another potential that has not been considered so far is to extend DesignChain to assembly and also have these scopes planned by an automated and digital chain.

7. Conclusion

Integrating DesignChain into order processing requires streamlining communication and collaboration between different departments and stakeholders. This integration enables efficient handling of customization requests, accurate production planning, and seamless coordination between design, manufacturing, and delivery processes. DesignChain ties in with the Y-CIM model, even if the business perspective has not been considered enough so far. Thus, DesignChain extends the established Y-CIM-Model and allows businesses to translate customer preferences into tangible products in a digitalized, automated and end-to-end integrated way. By involving customers at an early stage, companies can gather valuable insights, refine product concepts, and can ensure that the final product aligns with individual needs. This collaborative approach promotes innovation and enhances the overall customer experience. In conclusion, DesignChain serves as a catalyst for facilitating order processing of customized products. By effectively integrating and leveraging the DesignChain tool, businesses can meet the growing demand for customization. Thus, through the DesignChain production preparation effort can be reduced significantly as the degree of customization continues to increase.

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Biography

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