



Proposal for a system of personalized ordering integrated with cyber-physical systems

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Abstract: The growing demand for personalized products presents a major challenge to conventional manufacturing systems, which are typically optimized for mass production rather than customization. This paper presents the proposal of a service-oriented system of personalized ordering designed to integrate with cyber-physical manufacturing environments. Aimed at enabling product customization without compromising production efficiency. The proposed approach leverages modular architecture, asynchronous processing, and IoT-ready interfaces to enhance the production capability to cope with personalized products. The development process follows a structured methodology, including a literature review, system requirement specification, and architectural modeling using the C4 model. Although prototyping is ongoing, the architecture demonstrates strong feasibility, scalability, and alignment with Industry 4.0 principles.

Keywords: Industry 4.0. Personalized products. Customized products. Cyber-physical systems.

1. Introduction

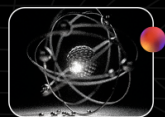
There has been a growing demand for product personalization across various sectors of manufacturing. Consumers increasingly seek products that reflect their individual preferences, including choices related to materials, colors, sizes, design features, and functionalities. This shift has driven the emergence of mass customization, a manufacturing paradigm that combines the efficiency of mass production with the flexibility of custom-made products. While mass customization offers the potential to enhance customer satisfaction and engagement, as noted by [1], it also introduces significant complexity to production planning and execution.

Despite technological advances, industries still face obstacles in adapting production systems to meet personalized demands efficiently. According to [2], one of the major challenges is the lack of integration and real-time communication between different components

of the supply chain. Moreover, the absence of intelligent, user-friendly interfaces that allow seamless customer interaction and customization hinders the widespread adoption of personalized ordering systems.

In response to these challenges, the rise of Industry 4.0, offers promising solutions. Industry 4.0 is defined by the convergence of digital technologies such as the Internet of Things (IoT), data analytics, and cyber-physical systems (CPS)[12]. CPS refers to the tight integration of computational algorithms and physical processes, where embedded systems monitor and control physical entities in real time [13]. In the manufacturing context, these technologies enable flexible and intelligent production environments capable of dynamically adjusting to individual orders based on real-time data.

There is still a gap in the implementation of service-oriented systems that effectively bridge customer-facing applications with backend CPS



infrastructures [3]. This research proposes the development of a service-oriented system of personalized ordering that integrates with both traditional and cyber-physical manufacturing environments. The system aims to provide a dynamic customization interface for customers while ensuring seamless communication with the production chain. The proposed solution will be implemented and tested in a pilot Industry 4.0 laboratory environment, aiming to validate its feasibility, usability, and integration capability.

The development process followed a structured methodology: beginning with a comprehensive literature review to identify relevant datasets, academic work, and existing applications; followed by the definition of system requirements, architectural design, and the development of a functional prototype. The prototype will undergo validation in controlled test scenarios aligned with the principles of Industry 4.0.

2. Literature review

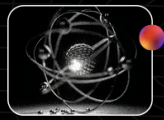
The literature review was organized into two primary areas of focus: the analysis of similar datasets and the examination of relevant scholarly articles.

No publicly available datasets closely aligned with the objectives of this research were identified. However, previous studies with related themes offer valuable insights. One such study by [5], highlights how the integration of cyber-physical systems (CPS) with the Internet

of Things (IoT) enables manufacturers to efficiently customize products according to individual customer needs, without compromising production speed or quality. Work by [6], presents a framework that supports rapid and cost-effective customization, even in complex and dynamic production environments. Additional articles were found to be particularly relevant for the potential future directions of this research. For instance, one study by [4], suggests that offering customized discounts can enhance customer engagement, going beyond the appeal of personalized products alone. Research by [8], emphasizes the importance of aligning artificial intelligence-based recommendation systems with human values and design thinking. The proposed framework aims to create personalization systems that are more ethical, inclusive, and user-centered. This could be further enhanced by combining it with advanced machine learning models such as Bi-GRU neural networks [10], offering both personalization and predictive capabilities.

3. System Requirements

System requirements define the expected behavior and constraints of the system, typically divided into functional and non-functional categories. Functional requirements describe the specific services and operations the system must perform, while non-functional requirements address quality attributes and operational constraints.



The primary functional requirements identified include:

- User registration and login with secure authentication mechanisms;
- An interactive product personalization interface;
- Submission of customized orders for fabrication;
- Integration between the application and the manufacturing system;
- Compatibility with mobile devices for broader accessibility.

The non-functional requirements include:

- Data security, through encrypted communication and regular data backups;
- Scalability, allowing for future feature expansion and increased user demand;
- Responsiveness, with real-time updates and performance under high data loads;
- Adaptability and flexibility, ensuring compatibility with various usage contexts, configurations, and IoT devices;
- System monitoring, including log tracking for diagnostics, auditing, and maintenance;
- Data persistence, achieved through structured and reliable storage in a relational database system.

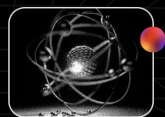
Collectively, these functional and non-functional requirements establish foundation for a robust, scalable, and adaptable system architecture, capable of delivering a secure and responsive

user experience while ensuring seamless integration with dynamic manufacturing environments.

3.1 System Structure

To document and communicate the software architecture in a clear and structured manner, the C4 model (Context, Container, Component, and Code) was adopted [11]. This model was chosen due to its ability to represent software systems at multiple levels of abstraction, offering a comprehensive yet concise way to describe the system to different stakeholders, including developers, designers, and non-technical audiences.

Although the C4 model provides four levels of architectural abstraction, this article will focus solely on the Container and Component diagrams. The Context diagram was omitted for brevity, as the system's external interactions are minimal. Similarly, the Code-level diagram was considered too extensive for the scope of this work. The Container and Component views, however, were selected as they provide sufficient architectural detail to understand the system's structure, responsibilities, and internal organization. These levels allow for a clear visualization of how the system is divided into deployable units and how responsibilities are distributed among internal components, which is essential for understanding its design decisions and implementation strategy.



As shown in Figure 1, the system's container diagram defines its core structure and external interactions. The architecture includes three main external systems:

- (i) A relational database, which fulfills the data persistence requirement and supports structured, secure storage;
- (ii) A manufacturing system, able to facilitate the execution of personalized product orders;
- (iii) A message queue, which enables asynchronous order handling and decouples services, supporting scalability and responsiveness.

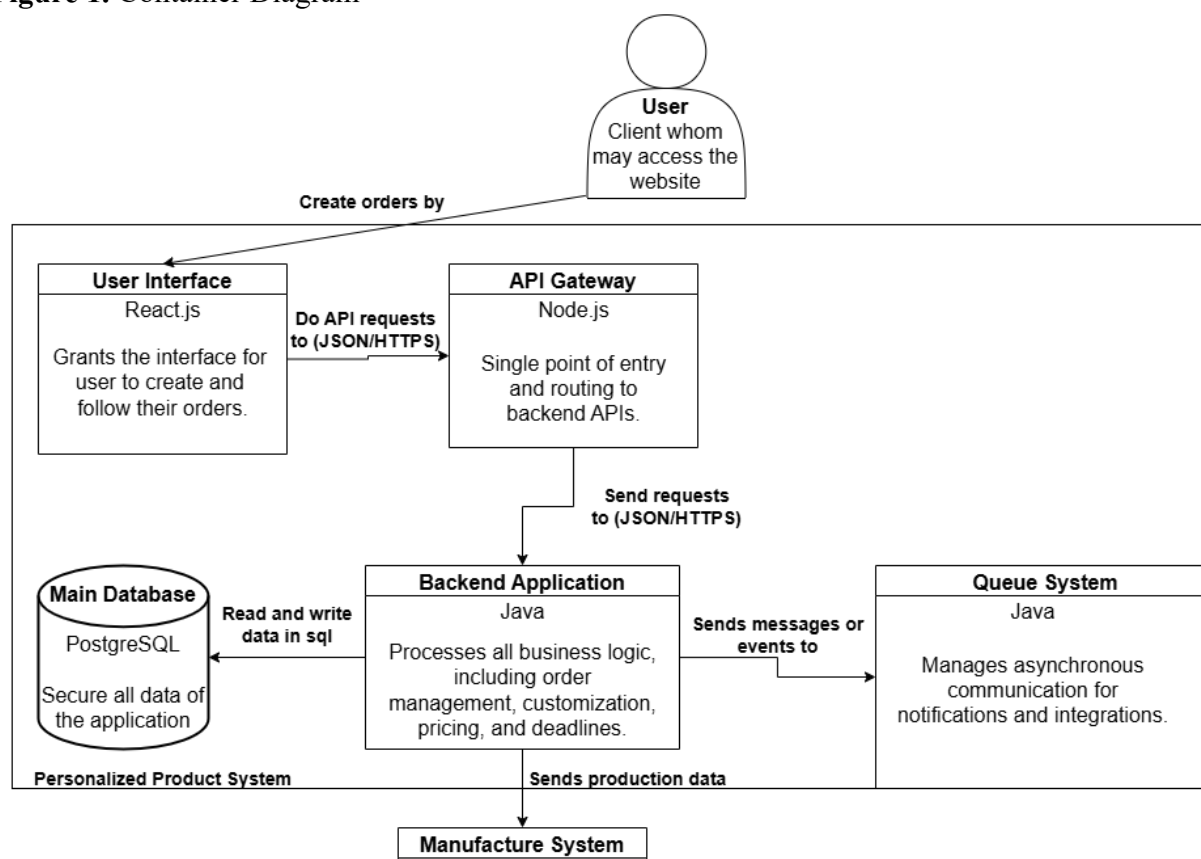
For a more granular view, Figure 2 presents the Component Diagram, detailing the internal modules of the system. Notably, it includes a dedicated authentication module, which

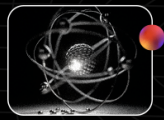
addresses the requirement for secure user login and registration. A personalization module reinforces the interactive customization interface, while an order management module is responsible for validating user inputs, calculating pricing and deadlines, and forwarding valid requests to the manufacturing pipeline.

Furthermore, adapter components ensure proper communication with external systems, supporting interoperability and system monitoring. Architecture also considers mobile accessibility through responsive front-end containers, ensuring that the system is compatible across devices.

By mapping architectural components directly to system requirements, the structure demonstrates

Figure 1. Container Diagram





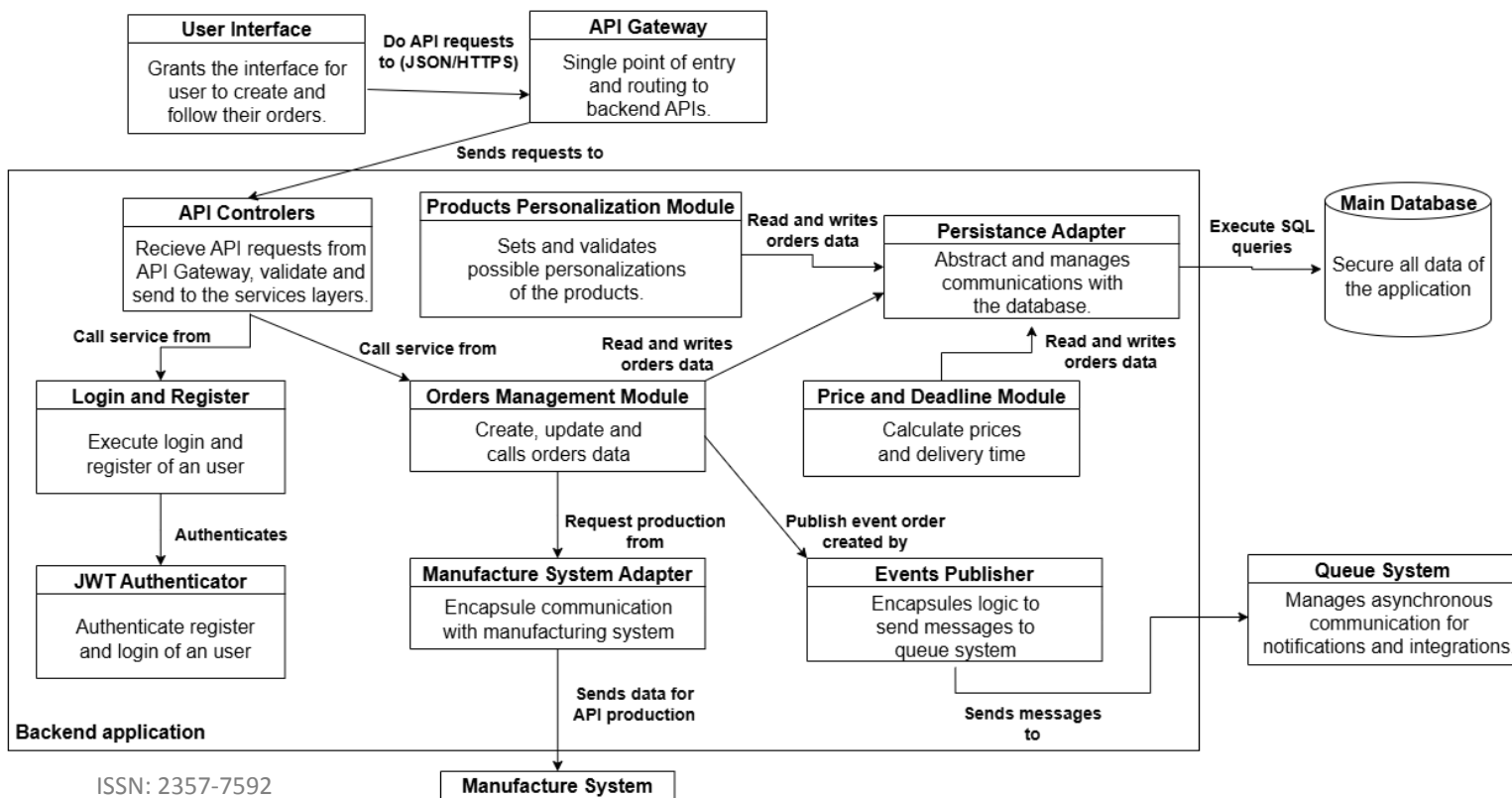
not only technical feasibility but also a strong alignment between design decisions and project objectives.

4. Prototyping

The prototyping phase had not yet been initiated. However, the software architecture previously defined, comprising well-isolated containers and clearly scoped components, offers a robust foundation for implementation. The modular structure of the system enables the independent development and testing of core functionalities, such as user authentication, product customization, order validation, and communication with external services.

The prototype is planned to be developed using a technology stack that supports scalability,

Figure 2. Components Diagram





employed for containerization of all services, ensuring consistency across environments and facilitating deployment, scaling, and service orchestration. Integration with a relational database such as PostgreSQL will support data persistence, while communication between services and components will be managed via a message queue system, such as RabbitMQ or Apache Kafka, enabling asynchronous processing and improving system decoupling.

To support continuous integration and continuous deployment (CI/CD), tools like Git, GitHub Actions, and Docker Compose will be considered. Testing will be supported through frameworks such as Jest for unit and integration testing, ensuring code quality and functional compliance.

The architecture's design ensures seamless integration with key components, including the database, manufacturing system, and message queue, through well-defined adapter interfaces. This minimizes service coupling and facilitates maintainability. Additionally, the use of containerization and asynchronous communication patterns supports the system's scalability and flexibility for future extensions.

Given these architectural and technological decisions, the transition from design to a working prototype is technically feasible and well-aligned with contemporary software engineering best practices, particularly those that

support service-oriented, scalable applications within Industry 4.0 contexts.

4.1 Validation Plan

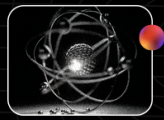
The prototype will be validated in a controlled Industry 4.0 laboratory environment to assess its usability, performance, and integration capabilities. The validation process will include:

- Functional Testing, ensuring all modules (authentication, personalization, order management) operate as intended.
- Integration Testing, verifying seamless communication with external systems (database, manufacturing system, message queue).
- User Acceptance Testing (UAT), involving end-users to evaluate the interface and customization experience.
- Performance Testing, measuring system responsiveness under high load and scalability thresholds.
- Security Auditing, validating encryption, authentication, and data integrity mechanisms.

Results will be quantitatively and qualitatively analyzed to identify improvements and ensure alignment with Industry 4.0 principles.

5. Conclusion

This work proposed a service-oriented system of personalized ordering designed to integrate seamlessly with cyber-physical manufacturing



environments, addressing the growing demand for product customization in the context of Industry 4.0. Through a structured methodology, comprising literature review, system requirement analysis, and architectural modeling using the C4 framework, the research established a solid foundation for implementing a scalable, modular, and maintainable system.

During this stage, it was also possible to conduct an in-depth investigation of the alternatives, methodologies, and technologies that will be used to meet business needs, especially regarding order capture and processing, as well as communication and integration with other systems - aligned with Industry 4.0 principles such as automation, customizations, and production efficiency.

While the proposed system promises enhanced customization and operational integration, its adoption is not without significant economic and implementation hurdles. A primary consideration is the substantial initial investment required for IoT infrastructure, CPS integration, and custom software development. Concurrently, organizations must budget for comprehensive workforce training to operate and maintain the new system. Further ongoing costs will be incurred to ensure interoperability with legacy systems and to maintain robust data security protocols. Despite these upfront challenges, the long-term return on investment, through increased customer satisfaction, reduced

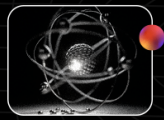
time-to-market, and greater production flexibility, is anticipated to justify the initial expenditure. A future cost-benefit analysis and pilot deployment in an industrial setting will be essential to quantitatively validate these economic assumptions.

The system architecture was carefully designed to enable asynchronous order processing, secure user authentication, dynamic customization, and real-time integration with external systems such as databases, manufacturing infrastructure, and message queue services. Although the prototyping phase had not yet begun at the time of writing, the detailed architecture demonstrates technical feasibility and alignment with modern software engineering best practices.

Future work includes the development and validation of a functional prototype in a controlled Industry 4.0 laboratory setting. This next phase aims to assess the system's usability, performance, and integration capacity in real-world scenarios, ultimately contributing to more efficient and customizable manufacturing workflows.

This approach not only addresses the limitations of current mass production systems but also lays the groundwork for more intelligent, user-centric manufacturing ecosystems aligned with Industry 4.0 standards.

6. Acknowledgements



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