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Application Methods of Digital Twin Technology in Quality Control and Management of Customised Furniture

Metode primjene tehnologije digitalnih blizanaca u kontroli i upravljanju kvalitetom namještaja po mjeri

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ABSTRACT • *Digital twin technology enables intelligent manufacturing and supports digital transformation. However, its use in customised furniture quality control is limited, due to issues such as inefficient traceability, slow response times, and predictive barriers. To address the fragmented quality management across stages, this study introduces a comprehensive framework that extends digital twins beyond workshops to the entire product lifecycle – design, warehousing, production, and after-sales. Adopting a design science research approach, we have developed a digital twin model for workshop quality control and a full lifecycle management approach, focused on three key pillars: lifecycle quality data management, high-fidelity virtual simulation, and real-virtual interaction. It thereby establishes a pathway to improve the accuracy and efficiency of quality control, which can lower costs, shorten delivery cycles, and accelerate digital transformation for furniture enterprises.*

KEYWORDS: *digital twin; quality control; customised furniture; smart manufacturing*

SAŽETAK • *Tehnologija digitalnih blizanaca omogućuje inteligentnu proizvodnju i podržava digitalnu transformaciju. Međutim, njezina je primjena u kontroli kvalitete namještaja po mjeri ograničena zbog problema kao što su neučinkovita sljedivost, sporo vrijeme odziva i prediktivne barijere. Kako bi se riješio problem fragmentiranog upravljanja kvalitetom u svim fazama, ova studija donosi sveobuhvatan okvir koji proširuje primjenu tehnologije digitalnih blizanaca izvan radionice, na cijeli životni ciklus proizvoda – dizajn, skladištenje, proizvodnju i postprodaju. Usvajajući pristup istraživanja znanosti o dizajnu, razvili smo model digitalnih blizanaca za kontrolu kvalitete u radionici, uz praćenje cjeloživotnog ciklusa proizvoda. Model je usmjeren na tri ključna stupa: upravljanje podatcima o kvaliteti životnog ciklusa namještaja po mjeri, na virtualnu simulaciju visoke vjernosti i na interakciju stvarno – virtualno. Time se uspostavlja put za poboljšanje točnosti i učinkovitosti kontrole kvalitete, što može smanjiti troškove, skratiti cikluse isporuke i ubrzati digitalnu transformaciju poduzeća koja se bave izradom namještaja.*

KLJUČNE RIJEČI: *digitalni blizanci; kontrola kvalitete; namještaj po mjeri; pametna proizvodnja*

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1 INTRODUCTION
1. UVOD

The advent of intelligent manufacturing has prompted furniture enterprises to adopt a distinctive Chinese approach. This approach features a large-scale, customised panel furniture intelligent manufacturing system and model (Xiong *et al*., 2022). This initiative enhances design, production, management, and service in furniture manufacturing. It has also improved furniture product quality control and gradually eliminated deficiencies in traditional processes. Instead of relying on the earlier 'extensive and family style quality management' model (Xiong *et al*., 2017), enterprises now use quality management information technology, digital quality tools, and greater efficiency to improve customised furniture board quality and control (Fang *et al*., 2020). However, as flexible production increases, key quality control processes become more complex. Real-time and predictive quality control are still suboptimal, making traceability, assessment, and avoiding later quality problems difficult. Therefore, state-of-the-art technology in intelligent manufacturing is essential to enable upgrades and comprehensively enhance quality control for customised furniture.

The concept of a Digital Twin (DT) can be traced back to the "mirror space model" proposed by Professor Michael Grieves in 2003 (Grieves and Vickers, 2016). NASA and the Air Force later used this concept for design, maintenance, and prediction (Shafto *et al*., 2010). A DT is a digital replica, synchronised in real time, of the state and behaviour of a physical entity. This replica is created by digitally mapping the entity elements. The concept integrates multiple physical domains, uses a multi-scale approach, incorporates surrealism, and employs dynamic probability to simulate real-world entities (Zhuang *et al*., 2017). DT possess five functions: mapping reality, dynamic updating, scene reproduction, autonomous thinking, and decision-making guidance. They support product design, process planning, equipment maintenance, quality control, and workshop construction. In recent years, DT have attracted more attention in intelligent manufacturing and have become a major focus for enterprises pursuing digital transformation.

This study aims to address the existing gap between DT technology and the quality control requirements of customised furniture production. The specific objectives are to: (1) propose a comprehensive application framework extending DT technology from the workshop to the full product lifecycle; (2) identify and analyse key technological enablers supporting this framework; and (3) establish a methodological foundation for intelligent, data-driven quality management. The overall goal is to deliver a systematic reference for both academic research and industrial implementation, thereby advancing the digital transformation of furniture manufacturing.

2 LITERATURE REVIEW
2. PREGLED LITERATURE

This section reviews literature in three areas: (1) an overview of DT technology in manufacturing enterprises; (2) its evolving application in the furniture industry; and (3) persistent gaps in quality control of customised furniture.

2.1 Overview of DT technology in manufacturing
2.1. Pregled tehnologije digitalnih blizanaca u proizvodnji

DT technology is a key strategy for the intelligent transformation of manufacturing. It connects physical and virtual domains and enables easy data transmission and sharing. The shared data include quantitative and qualitative data about materials and manufacturing processes, historical data, environmental data, and crucial real-time data (Singh *et al*., 2021). DT technology allows simulation, monitoring, diagnosis, prediction, and control of a product in the real world. It builds strong collaboration throughout the product lifecycle, boosting innovation in enterprises (Wu *et al*., 2020).

In manufacturing, the implementation of DT technology has advanced across multiple tiers, encompassing equipment, production lines, and the enterprise level. The following four key areas primarily manifest as follows: real-time monitoring and predictive maintenance; production process simulation and optimisation; product design and virtual testing; and full lifecycle management. It permeates the entire design, production, and operational maintenance process, gradually shifting from isolated technological breakthroughs to the construction of fully integrated, collaborative twin systems (Wang, 2025). This enhances transparency, flexibility, and sustainability across all stages of the product lifecycle, fostering effective collaboration between phases – from virtual design and prototyping to production planning, predictive maintenance, and after-sales service – thus propelling the intelligent innovation and upgrading of manufacturing. Consequently, DT technology signifies a paradigm shift from traditional experience-driven operational models to proactive, intelligent management approaches.

2.2 Application of DT in furniture industry
2.2. Primjena tehnologije digitalnih blizanaca u proizvodnji namještaja

DT technology is widely used in manufacturing for its transparency, predictability, and flexibility. The furniture industry, known for customised and flexible production, is a key area for DT exploration. This technology helps furniture makers address challenges such as integrating workshop information, identifying object flow, and intelligent scheduling (*Xiong et al*., 2024).

Most research on DT technology in the furniture industry focuses on the DT workshop. This model, based on DT technology, aims to optimise production and control. The DT workshop includes the workshop entity, virtual model, twin data, and service system. Compared to virtual and digital workshops, the DT workshop combines their advantages. It enables real interaction between the physical and virtual workshop (Li and Wu, 2023). The DT workshop also monitors and optimises workshop production lines, inspects product quality, and maintains equipment.

The concept of "Furniture Digital Twin Shopfloor (FDTS)" was first introduced by Ouyang *et al.* (2022) They developed a five-dimensional FDTS architecture and a "digital life form" model. They also described implementation steps and main technical areas for FDTS.

Wu and Zhu (2023) integrated the informatisation of customised panel furniture production with the DT shop floor. This integration aimed to address specific manufacturing challenges. They proposed five key dimensions for the DT shop-floor: physical, virtual, DT service, twin data, and data transmission. This five-dimensional model was created to solve information challenges in metal furniture production.

Bai (2023) developed a DT workshop model for a metal-furniture production line. This model was based on the prevailing DT framework and integrated the distinctive characteristics of metal furniture manufacturing. Xie (2024) developed a DT model and a virtual commissioning system. This system enables virtual commissioning, optimises production paths, and supports capacity planning. Its use has improved production efficiency, market responsiveness, and control over the production cycle.

Guo *et al* (2025) highlighted that integrating a DT system into the veneer defect repair production line facilitates data analysis and modelling. This enables optimisation of the repair line design by adjusting production parameters and improving equipment and processes, thereby increasing efficiency and reducing wear and tear on the production line.

The DT workshop for furniture, driven by DT technology, has taken shape, indicating the direction for implementing the DT system in the furniture industry. However, extant DT research primarily focuses on the general manufacturing industry and lacks adaptation to the dynamic production scenarios of customised furniture (Yan *et al*, 2021). Such scenarios include dynamic scheduling, process optimisation, quality inspection, equipment failure prediction, and packaging and transportation in various aspects.

2.3 Research gaps in quality control for customised furniture

2.3. Praznine u istraživanjima kontrole kvalitete namještaja po mjeri

Quality control can be defined as the process of organising and coordinating related activities to meet specific quality requirements (Wu *et al*., 2019). It is also an important competitive tool for modern furniture companies. In the context of custom furniture, quality control encompasses four critical phases: design, storage, production, and after-sales service. Poor design can result in substandard products that fail to meet quality expectations. The quality of raw materials on the incoming board directly affects the processing quality of the final product. Errors during production operations can lead to deformation, chipping, and warping. Post-sales service is vulnerable to inadequate packaging, transportation losses, and incomplete fittings, which complicates ensuring product safety (Ye *et al.*, 2019). These quality issues stem from the production process, which is the primary focus of manufacturing enterprises that prioritise control (Hu *et al*., 2023).

In accordance with the provisions of the "customised furniture quality inspection and quality assessment" and other pertinent national standards, most enterprises have established a quality management system, thereby implementing a more streamlined quality inspection (Figure 1).

Currently, many furniture manufacturers still rely on traditional manufacturing models or basic information-based quality control platforms (Xiong *et al*., 2018). Only a few companies, such as the Sophia Huanggang Factory, have truly adopted intelligent inspection systems that integrate technologies like vision and artificial intelligence (Xiong *et al*., 2018). The factory has two sets of quality inspection systems: one for the surface of the plate and a set for sealing quality. By using Charge-Coupled Device (CCD) ultra-high-speed imaging technology; this enterprise ensures product quality. Although the custom furniture industry in China has implemented the aforementioned quality control systems, there are still several significant shortcomings in the quality control of custom furniture based on the "Furniture Quality Traceability System Specification" issued by the Ministry of Industry and Information Technology and industry practices, which hinder efficiency, traceability, and quality consistency. The specific issues are as follows:

1) Low efficiency in tracing quality problems: Quality information for furniture products is dispersed across multiple departments, making assigning blame more difficult. This, in turn, affects the timely detection and resolution of problems, thereby reducing the efficiency of quality traceability. In addition, there is insufficient real-time monitoring of the pro-

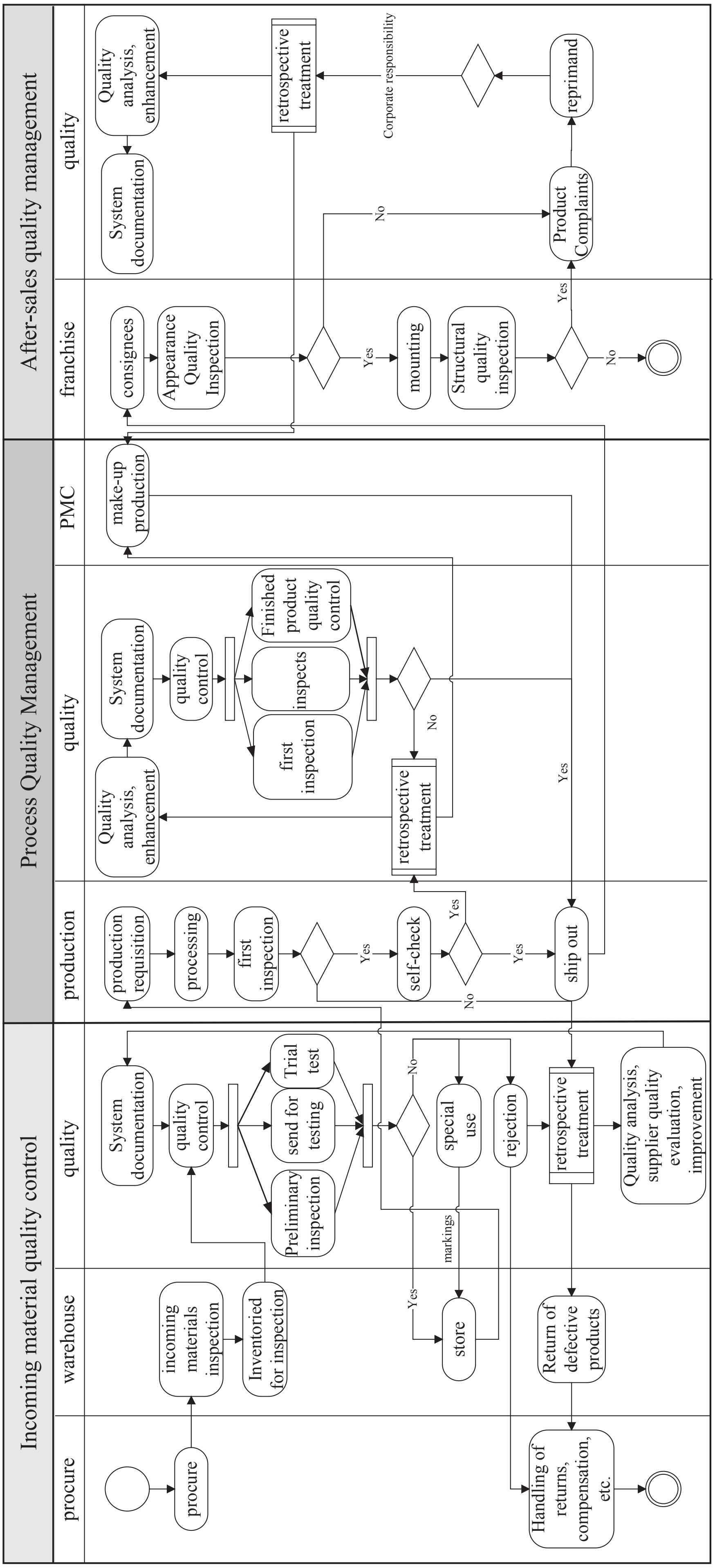

Figure 1 Customised furniture quality inspection management flowchart
Slika 1. Dijagram toka upravljanja kontrolom kvalitete namještaja po mjeri

duction process. As a result, the product production process is not transparent to quality control and is not traceable. This makes it difficult to determine the root cause of the quality problem, which, in turn, affects the efficiency of traceability.

2) Poor quality control timeliness: Throughout the life cycle of quality information acquisition technology, the methods employed are antiquated, predominantly manual record upload. This engenders an information lag, hinders managers' timely acquisition of feedback, complicates on-site problem resolution, and impedes the flow of information within the department. The degree of sharing is minimal, and the flow of information is inefficient, which adversely affects the quality of feedback transmission and, consequently, delivery and production plans (Fang, 2020).
3) Unreliable quality prediction: Enterprises must consider the six factors of "Man, Machines, Materials, Method, Environment (4M1E)" when making quality predictions (Cui *et al*., 2020). However, due to the high dimensionality, dynamics, and uncertainty of furniture product quality data (Lee *et al*., 2014), it is challenging to efficiently and reliably determine the impact of production variables on quality characteristics. This hinders the ability to support continuous quality optimisation.
4) The effect of quality improvement is not obvious: Furniture quality problems result from numerous factors, and improvement methods must address them comprehensively. However, the low efficiency of traceability hinders the effectiveness of surface improvement methods, necessitating repeated testing, which is both time-consuming and complex. This, coupled with the absence of quality assessment standards, results in a challenging situation in which the desired improvement may not be attainable.

This reveals that the core challenge in quality control for custom furniture lies in real-time monitoring and predictive control throughout its entire lifecycle. Currently, DT technology remains in its infancy for quality control applications in this sector, failing to provide a comprehensive, data-driven framework that bridges critical quality information gaps across different lifecycle stages. To address these deficiencies in existing quality control systems, this study aims to optimise production quality control processes and fill the research gap by developing an integrated DT framework and key technologies for full lifecycle quality management in custom furniture.

3 RESEARCH METHODS
3. METODE ISTRAŽIVANJA

This study adopts the design science research paradigm, following the systematic process from problem analysis to solution, aiming to develop a conceptual framework for quality control of the whole life cycle of customised furniture using DT technology, in order to solve the problem of fragmented quality control in the production of customised furniture. The study is grounded in multi-source evidence analysis, incorporating structured literature reviews, relevant national standards, technical reports, and observations of industry practices.

It proceeds through three sequential phases: First, it decomposes macro-level quality control challenges in custom furniture into four lifecycle-specific issues–design, warehousing, production, and after-sales service–and identifies stage-specific pain points using analysed evidence. Second, by aligning these pain points with DT technology core capabilities, it identifies critical intervention points and constructs key application models, establishing the logical foundation for full lifecycle quality control. Finally, it synthesises an integrated DT-driven lifecycle quality control framework, deriving the essential supporting technologies required for its implementation through both practical and theoretical reasoning.

4 RESULTS
4. REZULTATI

Based on the systematic analysis, this study has systematically developed the following core framework and key findings.

4.1 DT-driven quality control for customised furniture manufacturing workshops
4.1. Kontrola kvalitete vođena digitalnim blizancima za radionice koje proizvode namještaj po mjeri

The production workshop is the core arena for quality control. As the foundational scenario for implementing DT, we have first constructed an application model for workshop-level quality management, based on the FDTS architecture (illustrated in Figure 2).

This model aims to facilitate real-time data collection, analysis, and prediction within the production boundary. In this application model, quality information from the physical workshop is collected in real time. This includes:

- product quality information: size, shape, material and quality standard, etc;
- production process information: process flow information, process control information, and production progress information, etc.;
- equipment information: operation status, maintenance records, and failure statistics, etc;
- environment information: temperature, humidity, cleanliness, etc;

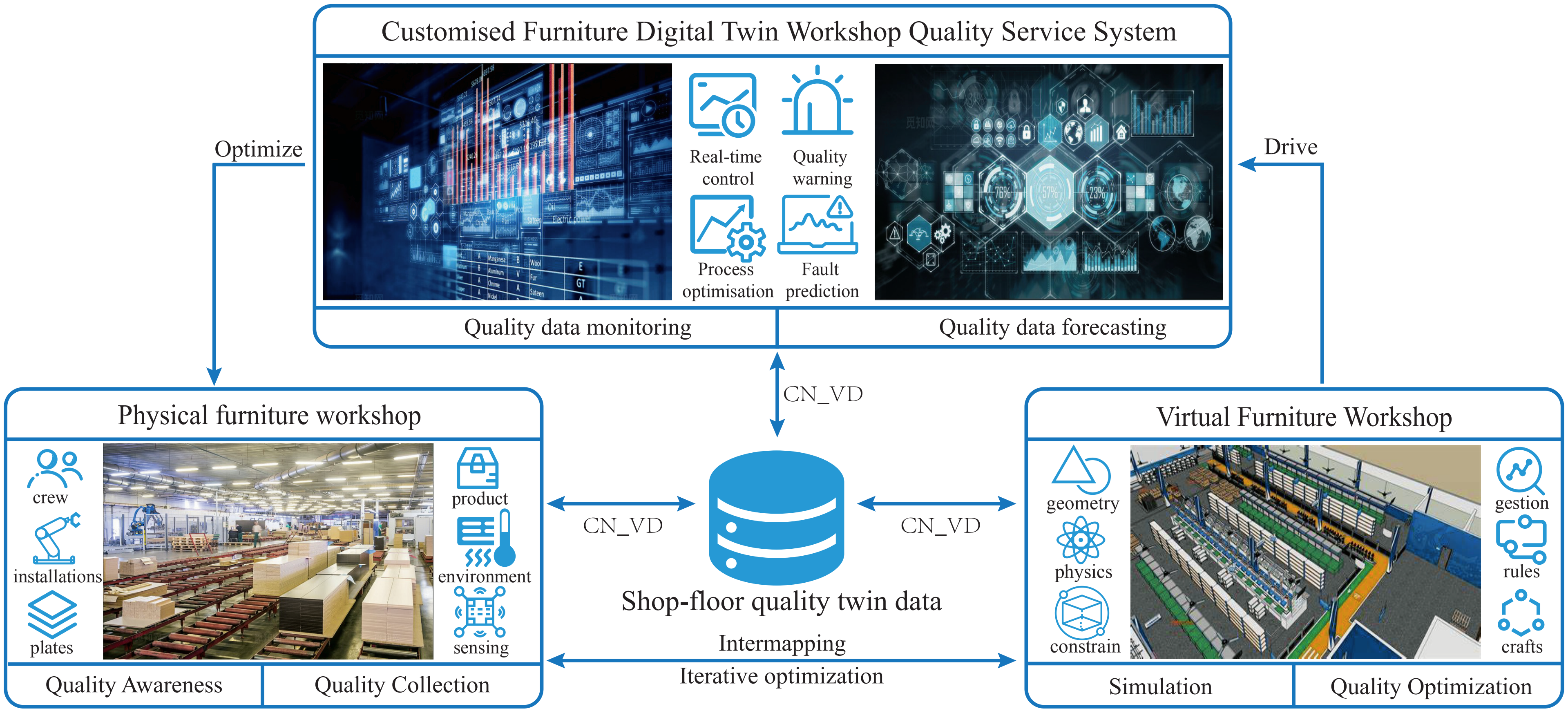

Figure 2 DT application model for quality control in customised furniture production workshop
Slika 2. Model primjene tehnologije digitalnih blizanaca za kontrolu kvalitete u radionici za proizvodnju namještaja po mjeri

- personnel information: location and status, etc, uploaded and stored as workshop quality twin data.

The virtual workshop realises simulation by analysing and predicting the workshop quality twin data and mapping it to the physical workshop; and the workshop quality service system is driven by the quality twin data output from the physical workshop and the virtual workshop to realise real-time management and control, process optimization, quality early warning, and fault prediction. The physical workshop, virtual workshop, and workshop quality service system are closely connected through the workshop quality twin data, which serves as the driver to support the iterative operation of production process quality information management, product quality control, and optimisation among the three.

4.2 Full lifecycle quality control framework extended from DT technology
4.2. Okvir kontrole kvalitete cijeloga životnog ciklusa namještaja po mjeri proširen tehnologijom digitalnih blizanaca

To transcend the limitations of this isolated workshop model and address the lifecycle-wide challenges identified in Section 2.3, we have proposed extending DT technology to encompass the entire product journey. Building upon the workshop model, an integrated full lifecycle management framework was proposed, as illustrated in Figure 3. In the design phase, a virtual model is constructed to simulate the production and usage environment and predict potential quality problems. In the warehousing phase, the stability of material quality is predicted using historical and real-time data to optimise purchasing efficiency. In the after-sales phase, installation quality is verified using the installation twin model, which simulates the steps, tool configurations, and actual conditions.

In this comprehensive process management framework, the integration of sensors and Internet of Things (IoT) devices (e.g., Radio-Frequency Identification (RFID) for tracking board batches; force sensors for monitoring sealing pressure; and visual sensors for detecting surface imperfections) establishes a comprehensive data chain for customised furniture. This encompasses the domains of design, procurement, production, and delivery to collect real-time quality parameters at each stage.

The implementation of a DT enables dynamic quality monitoring, automatically identifying problematic links and the responsible individual when abnormalities are detected. When anomalies are triggered, the system can automatically identify the problematic links and trace them back to the responsible person. Concurrently, the system can thoroughly analyse the data to identify the root causes of defects (e.g., panel cracking and warping).

The system can construct a prediction model by integrating historical and real-time data, data to predict the risk of the process and optimise the improvement strategy. Integration of quality data from multiple sources is feasible, and through multidimensional analysis, a visual signage board can be generated to guide parameter tuning and process iterations, ensuring that quality indexes throughout the life cycle remain stable and controllable.

The quality twin data of each stage of the customised furniture entire life cycle is stored, interacted with, and updated by a dynamic data model. The support model is adaptively adjusted to meet the quality control needs at different stages of the life cycle, thereby forming a closed-loop control system. This system enables precise quality management from the source to the end of the customised furniture life cycle.

4.3 Key enabling technologies for DT-driven quality control
4.3. Ključne tehnologije za kontrolu kvalitete vođenu digitalnim blizancima

The realisation of both the workshop model and the full lifecycle framework relies on breakthroughs in three key technological pillars, which are detailed below. These enabling technologies are essential for creating a closed-loop, DT-driven quality control system.

4.3.1 Full lifecycle DT quality data management
4.3.1. Upravljanje podatcima o kvaliteti dobivenim tehnologijom digitalnih blizanaca tijekom cijeloga životnog ciklusa namještaja po mjeri

In light of the growing demand for comprehensive quality management throughout the entire lifecycle of customised furniture, the primary technological challenge is to establish a unified, data-driven platform that facilitates effective collaboration and closed-loop management of cross-stage, multidimensional quality information (illustrated in Figure 4).

This DT quality data management platform encompasses the entire life cycle of customised furniture, incorporating quality data sources, collection, processing, and feedback. The quality data source comprises three components: first, quality information spanning the entire life cycle within the physical space; second, simulation information within the virtual space; and third, interaction data between the physical entity and the virtual model. Real-time quality data are collected through equipment during the production process, such as sensors, Programmable Logic Controllers (PLCs), RFIDs, and industrial control computers (Leng *et al.*, 2022).

The selection of collection modes, such as photos, videos, text, and data, is determined by the need for high-quality data analysis across various stages

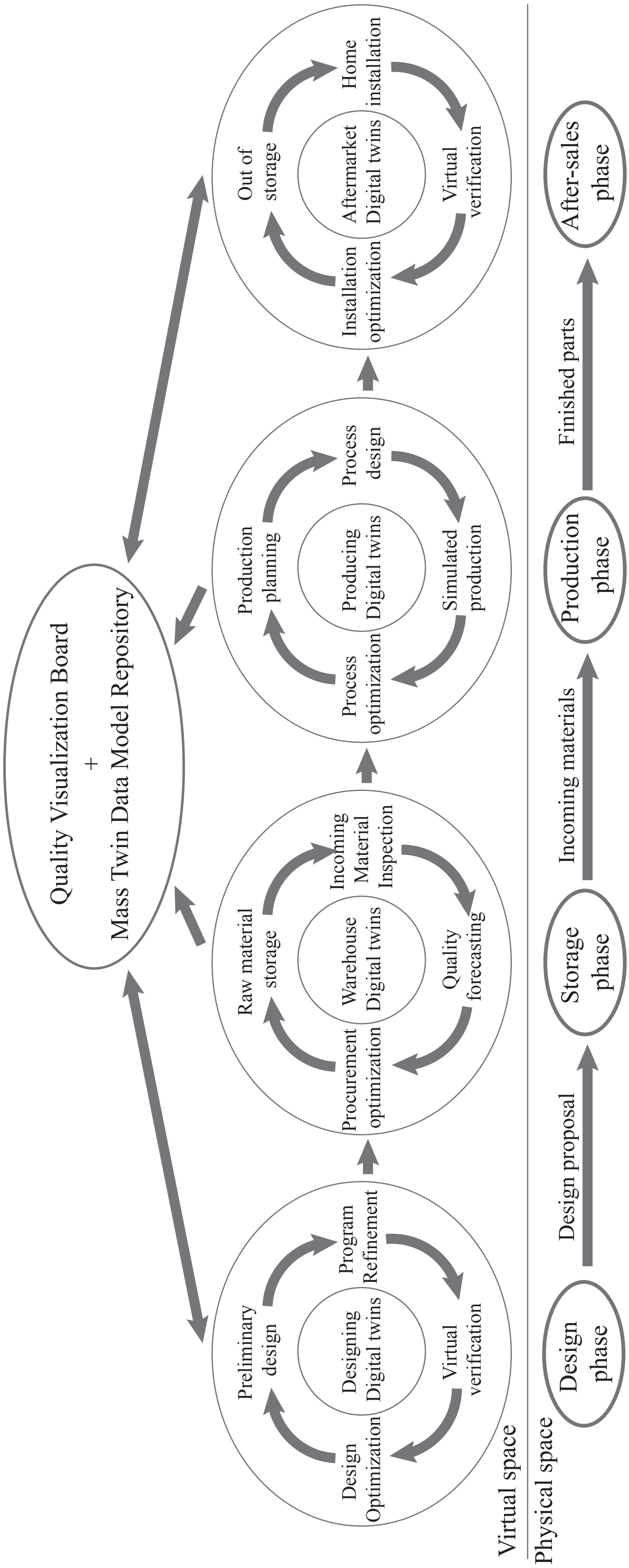

Figure 3 Full lifecycle management framework of customised furniture for DT technology
Slika 3. Okvir za upravljanje cijelim životnim ciklusom namještaja po mjeri uz pomoć tehnologije digitalnih blizanaca

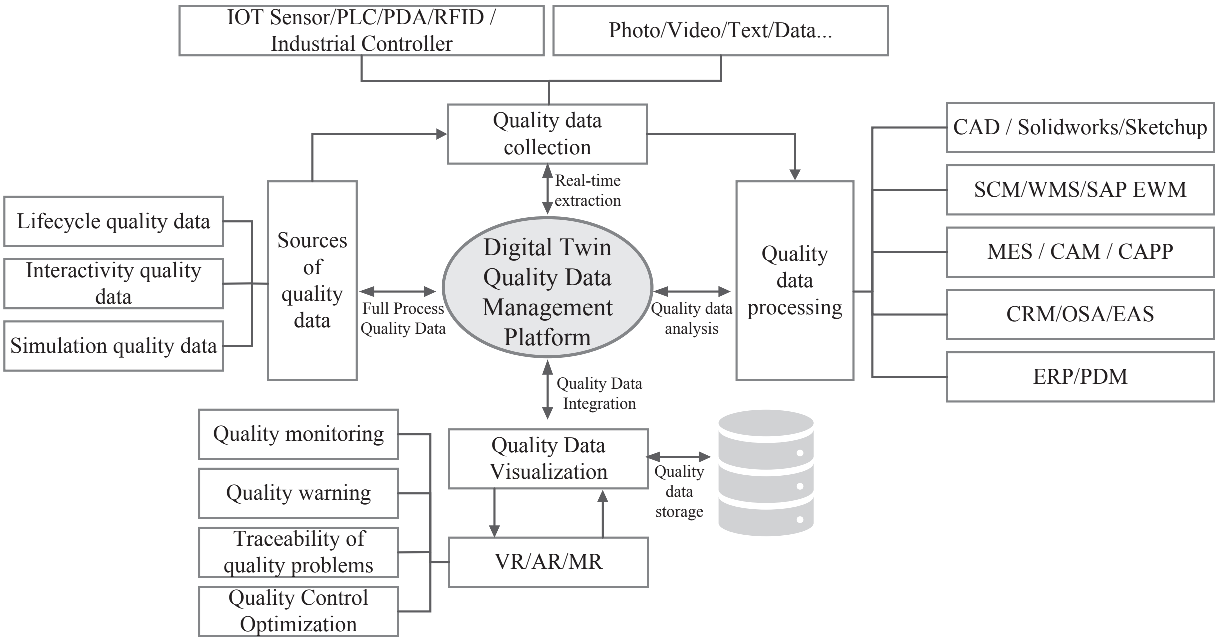

Figure 4 DT quality data management platform for the whole life cycle of customised furniture
Slika 4. Platforma za upravljanje podatcima o kvaliteti dobivenima uz pomoć tehnologije digitalnih blizanaca za cijeli životni ciklus namještaja po mjeri

(Kuo *et al*., 2022; Cao *et al*., 2021). The processing and feedback of quality data entail integrating quality information into the design process (e.g., CAD/ Solidworks/ Sketchup) and into the warehousing process. With logistics management software (e.g., SCM/ WMS/ SAP EWM), quality information in the production process with manufacturing software (e.g., MES/ CAM/CAP), after-sales process quality information and customer management and office software (such as CRM/OA/EAS) and the whole life cycle quality information and management software (such as ERP/PDM), etc., are integrated into the DT quality data management platform for analysis and processing, and through the VR/AR/MR technology to build the quality information visualization Kanban, intuitive feedback Quality data and abnormality localization.

The platform integrates the entire quality control data lifecycle, creating a closed-loop process that encompasses data collection, processing, storage, and feedback. This facilitates the end-to-end integration of quality information flow and promotes the quality control of customised furniture through an intelligent transformation from "experience-driven" to "data-driven".

4.3.2 Virtual model construction and simulation

4.3.2. Izrada i simulacija virtualnog modela

The construction of high-precision models constitutes the foundation of DT-driven quality control for the full life cycle of customised furniture (Tao *et al*., 2019). The high-precision model involved in the full life cycle of customised furniture is divided into four DT forms: design, storage, production, and after-sales (Cheng *et al*., 2021). The DT model is created vertically from six dimensions: geometry, physics, behaviour, rules, constraints, and processes. It is also created horizontally from six perspectives: Man-Machine-Material-Method-Environment-Measurement. Virtual reality mapping is also employed (Leng *et al*., 2022).

In the model construction, the material properties of the wood used are accounted for, including its physical, chemical, and mechanical properties. These properties are incorporated into the model as a critical parameter. The construction of high-precision digital models is facilitated by the utilisation of SolidWorks, Demo3D, and other three-dimensional tools. Ansys mechanical simulation is used to ensure model consistency with the physical entity. This comprehensive approach enables the mapping of furniture structure. The material properties (e.g., the hardness of the plate) and process flow (e.g., the "U"-shaped production line layout to balance the efficiency of the process) constraints on the operating range of equipment and AGV path planning (Gou *et al*., 2021) define the input and output of each process node, operation steps, and resource requirements, forming a standardised process framework.

Concurrently, integrating VR/AR technology enables the creation of a visual twin scene, thereby facilitating the dynamic display of the furniture physical state. This approach empowers users to adjust parameters in real time through an interactive interface, thereby optimising the quality prediction and improvement strategy. The integration of virtual and real linkage quality is realised throughout the entire process. Control, in the simulation, using COMSOL, Witness, and other software to build a dynamic model of the whole life cycle, by setting quality standards and testing methods, performing virtual product quality assessment, enabling real-time traceability of the root causes of production problems, and optimising and improving.

In the simulation, Witness and other software are utilised to construct a dynamic model of the entire life cycle. Quality standards and testing methods are established to evaluate the quality of virtual products. The root causes of production problems are traced in real time, and the improvement process is optimised and enhanced. Concurrently, the Simright finite element analysis tool can be used to import the furniture geometric model and define attributes to simulate the actual force and the virtual assembly process. This enables us to validate the precision of parts matching and optimise the structural design to improve quality and efficiency.

4.3.3 Real-virtual interaction technology
4.3.3. Tehnologija stvarne virtualne interakcije

The quality control of customised furniture oriented to DT technology is predicated on the realisation of equivalent expression of physical and virtual space. The establishment of bidirectional mapping between physical and virtual models focuses on multi-sensory real-time interaction, synchronised analogue simulation, and the application of 3R technology. Virtual-reality fusion collects real-time quality data, such as equipment status and production progress, in physical space via sensors, and relies on high-speed, stable, and low-latency transmission protocols to enable bidirectional interaction (Nie *et al*., 2024).

Between physical and virtual space, it is necessary to provide synchronised mapping of equipment, process, and production status based on high-precision models, and dynamic optimisation of quality control in physical space through the results of simulation, and to combine VR/AR/MR technology to build an immersive expression of physical and virtual space. The integration of AR/MR technology facilitates the construction of an immersive virtual-reality interaction scene (Guo 2019), intuitively presenting the behaviour and feedback of the DT model.

Concurrently, the integration of the Internet of Things, cloud computing, and artificial intelligence enables data-driven, collaborative decision-making between the real and virtual worlds (Cai *et al*., 2021), thereby establishing a closed loop of "sensing-simulation-optimisation" and enabling the dynamic integration of all elements of intelligent quality control.

5 DISCUSSION
5. RASPRAVA

The present study systematically constructs a DT workshop quality control model and an integrated framework spanning the entire lifecycle from design to after-sales service. The study directly addresses the fragmented research gap in quality control for custom furniture, resolving the inefficiencies of traceability and reactive quality management. Whilst extant research has proposed FDTS architectures and production line optimisation schemes (OuYang *et al*., 2022; Wu and Zhu, 2023), demonstrating the value of DT technology in enhancing localised efficiency during production phases, these approaches struggle to resolve systemic information silos between design, warehousing, production, and after-sales operations. Consequently, this study extends beyond local optimisation to achieve full lifecycle integration. The construction of a bespoke furniture-quality control framework, integrating multi-source data across the entire lifecycle, enables the integration of quality twin data from all stages. This establishes the fundamental prerequisites for predictive quality control and root-cause traceability.

Furthermore, the three key technologies proposed in this study do not merely offer generic solutions. The conceptual framework of custom furniture quality control is transformed into an actionable implementation roadmap, offering the industry a practical, technology-driven approach. However, the proposed solutions still have limitations, primarily because this integrated framework has not yet been fully deployed and validated in real-world corporate environments. Future case studies are urgently needed to demonstrate its practical benefits and expand the application scope of DT technology in the furniture industry.

6 CONCLUSIONS
6. ZAKLJUČAK

DT technology is a key enabler for the furniture industry to achieve intelligent manufacturing and industrial digital transformation. It will strongly support furniture enterprises in product quality control, flexible production, personalised customisation, and supply chain collaboration. This study moves beyond the prevalent workshop-centric application of DT technology in furniture research by proposing a holistic, lifecycle-encompassing quality control framework for customised furniture. The primary theoretical contribution lies in systematically bridging the identified research gap-fragmented quality management-through an integrated model that connects design, warehousing, production, and after-sales via a unified digital thread. In practical terms, this research provides a clear implementation roadmap for industry, shifting the paradigm from experience-driven, reactive quality checks to a data-driven, predictive, and closed-loop control system. Identifying three key enabling technologies offers actionable focal points for enterprises embarking on their digital transformation journey in quality management. In the future, with further research and development of DT technology, the shortcomings in real-time data collection, high-precision model construction, and virtual reality integration will be improved, and the deep integration with emerging technologies such as artificial intelligence and the Internet of Things will bring higher levels of intelligence to quality control, promoting the furniture industry to move towards intelligent manufacturing.

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