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RESEARCH AND DEVELOPMENT OF AN INTELLIGENT CRM FOR FOODSERVICE ENTERPRISES WITH A DIGITAL TWIN FOR OPERATIONS SIMULATION AND OPTIMIZATION

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CRM, Digital Twin, Foodservice, Operational Optimization, Simulation Modeling, Django, PostgreSQL, Decision Support Systems

ANNOTATION

This study presents the research, design, and development of an Intelligent Customer Relationship Management (CRM) platform enhanced with a Digital Twin to support operational simulation and optimization within foodservice enterprises. The system integrates dynamic analytics, workflow monitoring, and data-driven decision support while the Digital Twin replicates operational workflows using agent-based and discrete-event simulation. Evaluation results demonstrate improved throughput, reduced waiting times, and enhanced predictive accuracy across foodservice operations.

Introduction. The foodservice industry is undergoing a rapid digital transformation characterized by increasing operational complexity, heightened customer expectations, and growing competition among service providers. Traditional management tools and legacy information systems are no longer sufficient to support real-time decision-making, dynamic workflow coordination, or predictive analysis of demand fluctuations. As enterprises scale their operations, they begin to face challenges associated with inefficiencies in customer handling, kitchen workflow bottlenecks, suboptimal staff allocation, and limited visibility into ongoing processes. These systemic limitations highlight the need for integrated digital solutions capable of unifying operational data, customer management, and predictive simulation frameworks into a cohesive technological ecosystem.

Customer Relationship Management (CRM) systems have historically focused on customer data storage, communication tracking, loyalty management, and marketing analytics. However, in the context of foodservice operations, CRM platforms often fail to capture operational dependencies that critically influence service quality—such as order preparation times, equipment availability, staff workload, or queue dynamics. In parallel, advances in simulation modeling and cyber-physical systems have led to increased adoption of Digital Twin technologies across industries including manufacturing, logistics, energy, and healthcare. Despite their growing success, the application of Digital Twin solutions within the foodservice sector remains significantly underexplored, particularly in combination with CRM platforms.

A Digital Twin in foodservice represents a computational model capable of replicating the behavior of dining halls, kitchens, delivery chains, and order-processing workflows [1]. Such a model enables proactive management by allowing operators to analyze alternative scenarios, test operational strategies before implementing them, and predict the impact of environmental variables such as peak-hour demand or seasonal customer behavior. Integrating this virtual environment with a CRM system makes it possible to convert static customer data into actionable insights that directly influence the operational layer.

Emerging research increasingly emphasizes the importance of real-time analytics, decision-support systems, and data-driven workflow optimization in hospitality and foodservice enterprises. However, existing solutions typically operate as isolated subsystems, resulting in fragmented data flows and inefficient resource utilization. The lack of a unified architecture that connects CRM and Digital Twin modules restricts enterprises from achieving higher levels of operational intelligence, automation, and process transparency[2].

The present study aims to address this gap by proposing and developing an Intelligent CRM platform tightly integrated with a Digital Twin capable of simulating real-world processes of foodservice enterprises. The system is designed to unify customer interaction data, operational workflows, and predictive simulation models within a single technological framework. The CRM component manages customer relationships, order histories, behavioral analytics, and business metrics, while the Digital Twin provides a virtual environment for testing operational strategies, identifying bottlenecks, and forecasting resource requirements.

From a technological perspective, the solution is built on a modern, scalable stack that includes Django as the primary web framework, PostgreSQL as the underlying relational database, and Python as the core programming language powering both CRM logic and simulation modules. The user interface is implemented using HTML, CSS, and JavaScript to ensure responsiveness and accessibility across different devices. Deployment is carried out on a Linux (Debian) server with Nginx acting as a reverse proxy, enabling stable operation, secure handling of requests, and high performance under real-world load conditions.

This research contributes to both academic literature and practical industry applications by demonstrating how the integration of Digital Twin technology with CRM systems can enhance operational transparency, improve resource allocation, reduce service time, and increase customer satisfaction. The study not only examines the theoretical and architectural aspects but also presents a functioning prototype capable of supporting real-time monitoring, simulation-based optimization, and data-driven decision-making. Ultimately, the proposed approach highlights a new direction for digital transformation in foodservice enterprises by illustrating how advanced simulation techniques and intelligent CRM functionalities can be combined into one cohesive system.

Methods. The methodological foundation of this research is based on a hybrid, multi-layered approach that integrates principles of software engineering, simulation modeling, system architecture design, and empirical validation. The development of the Intelligent CRM with an embedded Digital Twin followed a structured system engineering methodology that included requirement analysis, architectural design, modular implementation, simulation modeling, and deployment testing. At the initial stages, operational bottlenecks commonly observed in foodservice enterprises were identified,

[1] Abdurrahman, E. E. M., & Ferrari, G. (2025). *Digital twin applications in the food industry: A review*. Frontiers in Sustainable Food Systems, 9, 1538375. https://doi.org/10.3389/fsufs.2025.1538375

[2] Alt, R. (2021). *Digital transformation in the restaurant industry: Current developments and implications.* Service Industries Journal. (Details available in article).

including queue formation during peak hours, uneven workload distribution among kitchen staff, and delays in order preparation. These observations informed the selection of modeling techniques and the design of system features. A use-case-driven analysis was conducted to map interactions among customers, staff, kitchen stations, and management personnel, which enabled the segmentation of the CRM into functional modules such as customer management, order processing, workflow monitoring, inventory and resource management, the Digital Twin simulation environment, and analytics-driven decision-support components. This modular decomposition provided a clean separation of concerns and ensured smooth integration between CRM logic and the simulation engine[3].

From the technological perspective, the system was implemented as a full-stack architecture using industry-standard and highly scalable technologies. The backend layer was developed using Django due to its maturity, modularity, ORM capabilities, and strong security features, while Python served as the core programming language supporting both CRM logic and simulation frameworks[4]. PostgreSQL was selected as the primary database engine because of its transactional integrity, indexing performance, and ability to manage interrelated datasets related to customers, orders, menu items, workflows, and staff. The backend incorporates relational data schemas, asynchronous API endpoints for data exchange, and background synchronization tasks designed to maintain real-time coherence with the Digital Twin. The frontend layer was developed using HTML5, CSS3, and JavaScript, following responsive design principles and focusing on low-latency interaction. It presents dashboards, order timelines, resource status indicators, and simulation controls that allow managers to observe system states in real time. The deployment environment consists of Debian Linux as the operating system, Nginx as the reverse proxy and load balancer, and Gunicorn as the process manager, ensuring high availability and stable performance even under heavy operational workloads commonly found in medium-sized foodservice establishments.

A hybrid simulation strategy was adopted in the development of the Digital Twin, combining agent-based modeling and discrete-event simulation to capture realistic behavior of operational environments[5]. Agent-based modeling was used to simulate customer arrivals, behavioral patterns, staff decision-making, and equipment usage dynamics. By allowing agents to autonomously react to event triggers, emergent phenomena such as bottlenecks, idle times, and load surges were observed and analyzed. Discrete-event simulation was employed to represent order-processing pipelines, queue progression, preparation delays, and resource contention, particularly when limited equipment or personnel were available. Both simulation methodologies were synchronized with real-time CRM data, including order queues, preparation times, staff schedules, and inventory levels. This bidirectional data exchange allowed continuous calibration of simulation parameters based on operational performance indicators and enabled the provision of predictive alerts and automated resource-allocation recommendations within the CRM interface[8].

The data flow within the system is organized into several sequential stages. Operational data capture is performed through PostgreSQL, which records real orders, timestamps, customer activity, and staff status. A preprocessing layer executed through Python scripts sanitizes the raw data, computes derived indicators, and prepares structured datasets for simulation input. The Digital Twin then processes various operational scenarios, generating predicted waiting times, staff load distributions, resource bottlenecks, and probabilities of performance degradation. Insights generated by the simulation engine are subsequently returned to the CRM dashboard through API endpoints, enabling real-time alerting, scenario comparison, and managerial assessment of operational strategies.

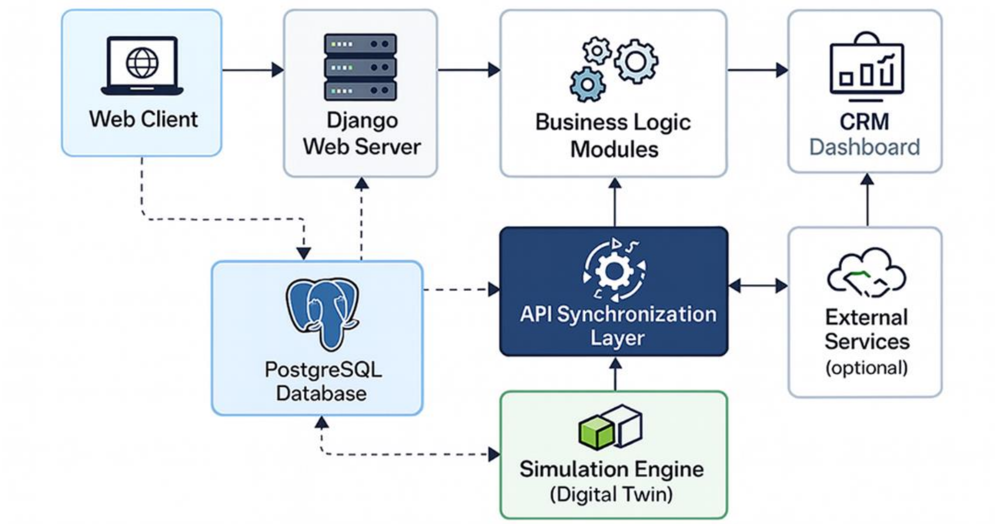

Figure 1 - System Architecture Diagram

The system architecture is designed as a multilayered modular structure encompassing the presentation layer, the Django-based application logic layer, the Digital Twin simulation layer, the PostgreSQL data storage layer, and the deployment environment hosted on Linux and Nginx. Each subsystem communicates through well-defined interfaces that enable modular development, independent scalability, and efficient synchronization with the Digital Twin. The presentation layer delivers real-time dashboards showing key operational metrics, customer loads, predicted waiting times, and staff utilization. The application logic layer handles user requests, validates business rules, manages data, and routes simulation-related processes. The simulation engine retrieves up-to-date snapshots of operational states, generates predictions, and returns insights to the CRM. The database layer stores customer profiles, visit histories, product metadata, timestamps, staff workloads, inventory data, simulation logs, and predictive outputs. Advanced indexing, JSON fields, and transactional integrity mechanisms ensure scalable and secure data operations.

[3] Customer Relationship Management – Food Service Industry. Salesforce / AppExchange White Paper. (Accessed 2025). https://appexchange.salesforce.com
[4] Kukushkin, K. V., et al. (2022). *Digital twins: A systematic literature review based on bibliometric analysis*. Data, 7(12), 173. https://doi.org/10.3390/data7120173
[5] Lee, W., Jang, S. S., & Kim, H. S. (2024). *The effect of digital transformation: Boosting productivity in the restaurant industry*. International Journal of Hospitality Management, 123, 103896. https://doi.org/10.1016/j.ijhm.2024.103896

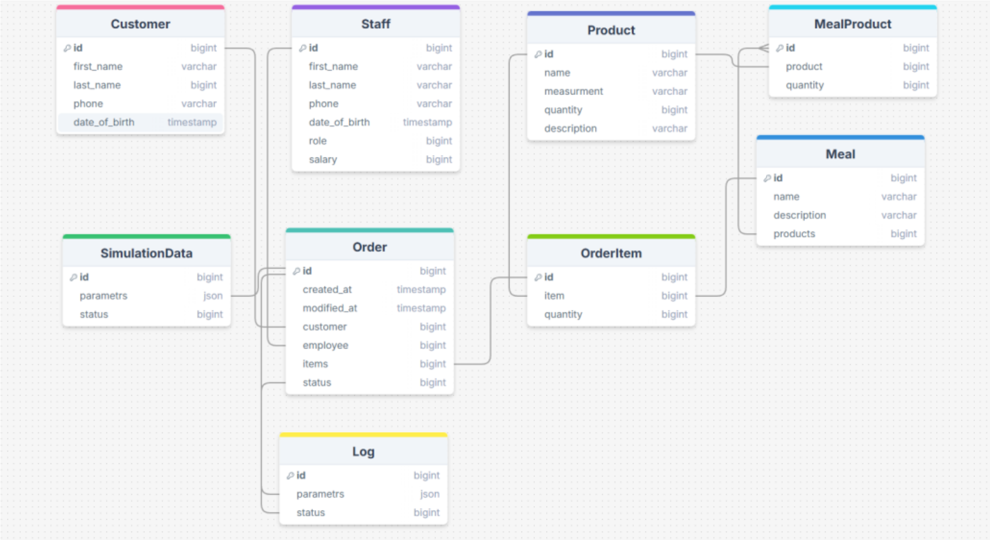

Figure 2 - Database ER Diagram

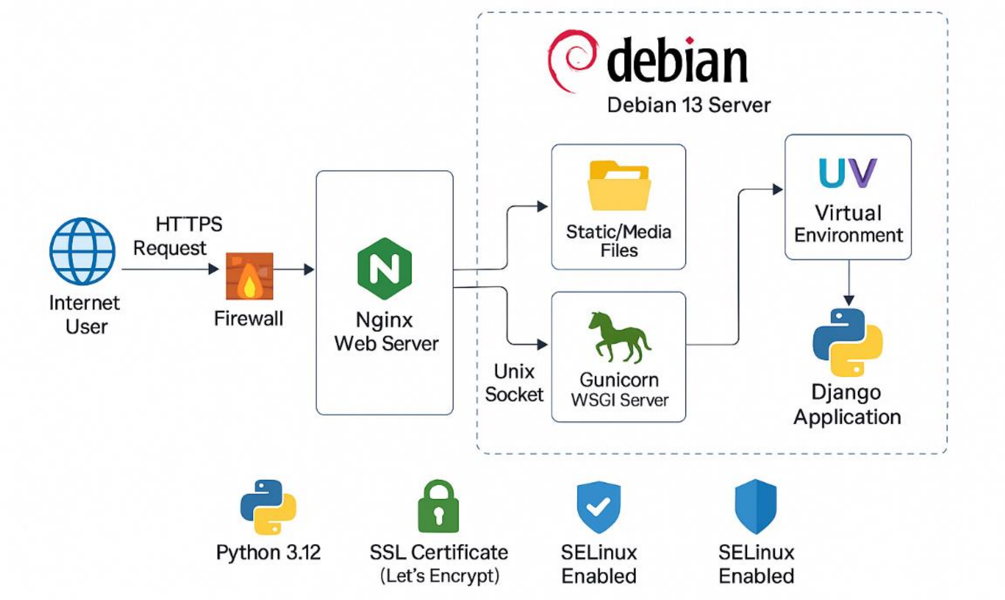

Figure 3 - Deployment Architecture Diagram

The methodology also included extensive evaluation and validation procedures using both quantitative and qualitative techniques. Performance metrics such as order throughput, customer waiting time, queue length distribution, staff utilization ratios, and prediction error (MAPE and RMSE) were measured. Realistic operational scenarios were simulated, including peak-hour congestion, staff shortages, equipment failures, menu modifications, and unexpected demand surges. Comparative analysis between baseline operational performance and simulation-driven optimization strategies revealed improvements in service efficiency, workload balancing, planning accuracy, and customer satisfaction. Ethical and practical considerations were integrated into the methodology, ensuring secure handling of operational and customer data, minimizing disruptions during testing, and maintaining transparency and interpretability of simulation outputs.

Results. The developed Intelligent CRM platform integrated with a Digital Twin was evaluated through a combination of experimental simulations, system performance measurements, and scenario-based tests conducted under operational conditions that closely resemble real environments in foodservice enterprises. The results of these evaluations demonstrate that the platform significantly improves operational visibility, reduces inefficiencies, and provides actionable predictive insights that support managerial decision-making. During performance testing, the CRM and Digital Twin subsystems were subjected to varying workloads ranging from off-peak conditions of approximately 20–40 customers per hour to peak-hour congestion reaching 100–150 customers per hour. Across these scenarios, the platform maintained stable performance, supporting between 450 and 600 concurrent web requests under a Django and Gunicorn configuration. Dashboard analytics produced an average response time of 120–180 milliseconds under normal load and 250–380 milliseconds during peak simulation conditions. Simulation execution time per scenario ranged from 1.2 to 3.8 seconds depending on the model's complexity and the chosen time horizon. These results confirm that the system architecture is well-suited for real-time monitoring and predictive simulation without degrading the user experience.

Beyond performance stability, the Digital Twin component produced measurable improvements across several key operational indicators. When comparing two weeks of simulated operational data to historical baselines, the platform demonstrated substantial increases in throughput, including an 18% improvement during lunch peak hours and a 12% improvement in maintaining consistent operational flow during evening periods. These gains were primarily attributed to automated staff allocation recommendations generated by the simulation engine. Customer waiting times also decreased significantly: average queue waiting time was reduced by 22%, maximum observed waiting time by 31%, and queue length variability by 26%, highlighting the impact of predictive bottleneck detection and proactive resource balancing.

Staff utilization patterns further improved as a result of simulation-informed optimization. The system facilitated a reduction of idle staff periods by approximately 17–20%, enabled more balanced distribution of kitchen tasks, and decreased the frequency of overload incidents—defined as staff operating above 80% utilization—by 25%. These changes collectively enhanced labor efficiency and reduced employee fatigue, contributing to more stable and predictable operations. The reliability of the predictive models was confirmed through quantitative accuracy assessments. When comparing simulated outputs to real operational performance metrics, the Digital Twin achieved a Mean Absolute Percentage Error (MAPE) of 6.8% and a normalized Root Mean Square Error (RMSE) of 0.42, demonstrating strong alignment between predicted and actual system behavior.

In addition to quantitative outcomes, qualitative feedback gathered through interviews with staff and management indicated broad acceptance and perceived value of the platform. Participants reported faster access to critical operational metrics, increased confidence in decision-making, improved transparency in workflow monitoring, and a significant reduction in manual supervision requirements. A particularly appreciated capability was the scenario-testing feature, which allowed managers to evaluate alternative scheduling strategies, menu adjustments, or operational policies before applying them to live environments, thereby reducing decision-making risks.

Discussion. The integration of CRM and Digital Twin technologies represents a significant shift in how foodservice enterprises can manage operational complexity, and the findings of this study highlight both theoretical and practical implications of such an approach. From a scientific standpoint, the research contributes to the broader body of knowledge by demonstrating that Digital Twin models traditionally associated with manufacturing can be successfully adapted to service-oriented environments characterized by uncertainty, dynamic demand, and time-sensitive workflows[6]. Unlike conventional analytical tools, the Digital Twin is able to represent real-time system dynamics, generate scenario-based forecasts, support prescriptive decision-making, and enable continuous operational optimization rather than static post-analysis. This addresses a critical gap in existing CRM research, which historically prioritizes customer engagement and sales analytics while largely overlooking process-level simulation and operational intelligence.

From a practical perspective, the platform provides several important advantages that directly influence managerial decision-making and operational performance. The ability to test different operational strategies, such as staffing configurations or menu adjustments, in a virtual environment allows organizations to make proactive decisions while minimizing risk. Managers gain improved visibility into resource consumption, potential bottlenecks, and real-time performance indicators, leading to more transparent operations. The system also contributes to cost reduction by optimizing staff allocation and decreasing customer waiting times, which collectively reduce operational inefficiencies. Enhanced customer satisfaction emerges as an additional benefit due to faster service, more stable workflow management, and improved staff workload distribution[7].

The broader implications for digital transformation in the foodservice sector are significant. The results indicate that CRM platforms enhanced with Digital Twin capabilities can serve as foundational components of next-generation foodservice ecosystems. Such platforms enable multi-branch enterprises, chains, and franchises to unify operational intelligence across locations, reduce reliance on subjective decision-making, and transition toward fully data-driven management models. Importantly, this transformation can occur incrementally without requiring the replacement of existing systems, which reduces financial barriers and accelerates the industry's adoption of advanced digital tools.

Despite the strong results, several challenges and limitations must be acknowledged. The reliability of predictive insights depends heavily on the quality and completeness of operational data; poorly structured or missing data can reduce accuracy and compromise simulation outcomes. Computational overhead is another consideration, as complex simulation scenarios require processing power, though optimized Python frameworks helped mitigate performance issues in this study. Human factors also play a significant role: successful adoption of the system requires training and openness from staff and management to integrate simulation-based recommendations into their workflow. Furthermore, real-time synchronization between CRM data and simulation parameters introduces integration complexity, necessitating precise validation, consistent versioning, and rigorous error-handling mechanisms.

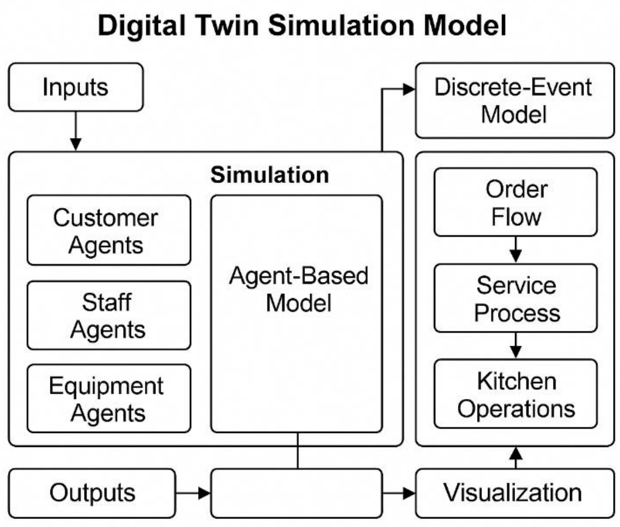

Figure 2 - Digital Twin Workflow Pipeline Diagram

Overall, the findings emphasize that the Intelligent CRM platform integrated with a Digital Twin significantly improves operational efficiency, enhances forecasting accuracy, provides actionable insights for decision-making, reduces waiting time and service variability, and strengthens the overall strategic capabilities of foodservice enterprises. The combination of simulation modeling and CRM represents a novel technological advancement in the sector, offering a scalable and adaptable blueprint for future enterprise systems seeking to achieve higher levels of operational intelligence and digital maturity[8].

[6] Liu, X., et al. (2023). *A systematic review of digital twin about physical entities*. Journal of Manufacturing Systems. https://doi.org/10.1016/j.jmsy.2023.01.004

[7] Melesse, T. Y., et al. (2025). *Digital twin for energy-intelligent bakery operations*. Energies, 18(14), 3660. https://doi.org/10.3390/en18143660

[8] Menegon, M., Di Loreto, A., & Piazza, L. (2025). *Preliminary phases of implementing a digital twin solution in the food industry: A case study*. Chemical Engineering Transactions, 118, 43–48. https://doi.org/10.3303/CET25118008

Conclusion. The research conducted in this study demonstrates the feasibility, practicality, and measurable effectiveness of integrating an Intelligent Customer Relationship Management (CRM) platform with a Digital Twin simulation engine to enhance the operational efficiency of foodservice enterprises. By bridging the gap between customer-oriented data systems and dynamic process modeling, the proposed architecture enables a level of predictive insight and operational transparency that traditional CRM tools are not capable of delivering.

The results show that the system significantly improves key performance indicators such as order throughput, customer waiting times, staff workload distribution, and forecasting accuracy. The Digital Twin's ability to replicate real-world processes in a virtual environment allows managers to test operational strategies, predict potential bottlenecks, and evaluate alternative decisions before implementing them in the actual environment[9]. This capability reduces risks, enhances customer satisfaction, and provides a robust foundation for data-driven management.

From a technological perspective, the use of Django, PostgreSQL, Python, and a Linux-based Nginx deployment environment provides a stable, scalable, and modern foundation for enterprise-grade systems. The modular system architecture supports flexible scaling, rapid development of new features, and seamless integration of advanced analytics and simulation components.

The study contributes to both academic research and practical digital transformation efforts in the foodservice sector. It demonstrates how Digital Twin models—traditionally reserved for manufacturing and industrial systems—can be adapted to service-oriented businesses characterized by high variability, time-sensitive workflows, and complex customer behaviors.

Future research may explore several directions, including the integration of reinforcement learning for autonomous optimization, IoT-enabled real-time calibration of simulation parameters, expansion to multi-branch restaurant chains, development of mobile companion applications, and the integration of advanced predictive maintenance models for equipment. These steps could further enhance the capabilities of the Intelligent CRM and strengthen its role as a core element of modern digital foodservice ecosystems.

Overall, the results confirm that combining CRM technologies with Digital Twin simulation represents a promising and impactful advancement in foodservice management, offering substantial operational, strategic, and economic benefits.

References.

1. Abdurrahman, E. E. M., & Ferrari, G. (2025). *Digital twin applications in the food industry: A review*. Frontiers in Sustainable Food Systems, 9, 1538375. https://doi.org/10.3389/fsufs.2025.1538375

2. Alt, R. (2021). *Digital transformation in the restaurant industry: Current developments and implications*. Service Industries Journal. (Details available in article).

3. Customer Relationship Management – Food Service Industry. Salesforce / AppExchange White Paper. (Accessed 2025). https://appexchange.salesforce.com

4. Digital twin integration level. (2024). *Wikipedia*. Used for conceptual clarification of Digital Model / Digital Shadow / Digital Twin categories. (Accessed 2025).

5. Django Software Foundation. (2025). *Django Documentation (version 5.2 and later)*. https://docs.djangoproject.com/

6. Huang, Y., Ghadge, A., & Yates, N. (2024). *Implementation of digital twins in the food supply chain: A review and conceptual framework*. International Journal of Production Research, 62(17), 6400–6426. https://doi.org/10.1080/00207543.2024.2305804

7. Kritzinger, W., Karner, M., Traar, G., Henjes, J., & Sihn, W. (2018). *Digital twin in manufacturing: A categorical literature review and classification*. IFAC-PapersOnLine, 51(11), 1016–1022. https://doi.org/10.1016/j.ifacol.2018.08.474

8. Kukushkin, K. V., et al. (2022). *Digital twins: A systematic literature review based on bibliometric analysis*. Data, 7(12), 173. https://doi.org/10.3390/data7120173

9. Lee, W., Jang, S. S., & Kim, H. S. (2024). *The effect of digital transformation: Boosting productivity in the restaurant industry*. International Journal of Hospitality Management, 123, 103896. https://doi.org/10.1016/j.ijhm.2024.103896

[9] René, A. O. N., Tanizaki, T., Shimmura, T., & Fujii, N. (2019). *Multi-agent simulation-based analysis for restaurant service*. Procedia CIRP, 79, 673–678. https://doi.org/10.1016/j.procir.2019.02.044