A Competency Framework for Implementing Green Digital Twins in the Beverage Industry: Survey Insights and Role Recommendations

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***Abstract*— The implementation of green digital twins (GDTs) in the beverage industry requires a precise alignment of roles and competencies to ensure success. GDTs offer significant opportunities to enhance sustainability, energy efficiency, and compliance with environmental, social, and governance (ESG) standards. However, practical implementation hinges on a clear understanding of the required expertise and the allocation of responsibilities across key organizational roles. This study evaluates whether four predefined roles—Orchestrator, Domain Expert, IT, and Management—are sufficient to address the competencies needed for GDT deployment. A survey conducted with industry experts assessed 49 competencies across eight categories, ranging from domain-specific knowledge to advanced data engineering and sustainability practices. The results reveal significant competency gaps in areas such as programming, sensor integration, ESG reporting, and data engineering. These gaps underscore the necessity of introducing additional roles, such as Data Engineer, ESG Manager and Process Engineer, to complement the existing framework. By analyzing competency strengths and deficiencies, this paper proposes a refined competency framework that ensures a holistic approach to GDT implementation. The recommendations aim to guide practitioners and decision-makers in aligning organizational resources with the demands of sustainable digital transformation in the beverage sector.**

Index Terms—Digital Twin, manufacturing, energy system, process industry, requirements, sustainability

I. Introduction

The global transition towards sustainable industrial practices has led to an increased focus on digital technologies that optimize resource efficiency and reduce environmental impact. One such innovation is the Green Digital Twin (GDT), a concept that integrates real-time data, simulation models, and artificial intelligence to improve operational efficiency and sustainability in industrial settings.

The beverage industry, particularly breweries, is under increasing pressure to align with global sustainability strategies. A promising approach to enhance sustainability is the integration of GDTs, which leverage digital tools to optimize processes and reduce environmental impact.These digital replicas of physical production environments enable manufacturers to monitor energy consumption, optimize supply chains, and ensure compliance with stringent environmental regulations. However, the successful implementation of GDTs requires a multidisciplinary approach that incorporates expertise from various domains, including information technology, process engineering, and sustainability management. Despite the increasing interest in GDTs, a significant challenge remains: the lack of a clearly defined competency framework that outlines the necessary skills and roles required for their implementation. Existing research has primarily focused on the technical aspects of Digital Twins (DT), neglecting the human factors essential for their deployment. Without a structured approach to competency development, organizations risk inefficiencies, misalignment between teams, and suboptimal utilization of GDT capabilities.

This paper aims to bridge this gap by evaluating whether four predefined roles—Orchestrator, Domain Expert, IT and Management—adequately cover the competencies required for implementing GDTs in the beverage industry. Through a structured survey involving industry experts, we identify competency gaps and propose additional roles necessary to support the adoption of GDTs. By providing a competency framework, this research contributes to the ongoing discourse on digital transformation and sustainability, offering actionable insights for both academia and industry practitioners. The remainder of this paper is structured as follows: Section 2 reviews related work, discussing prior research on digital twins, competency frameworks, and role models in industrial settings. Section 3 presents the methodology used to collect and analyze competency data. Section 4 outlines the key findings, highlighting areas of strength and deficiency. Section 5 discusses the implications of these findings and the necessity for additional roles. Section 6 provides recommendations for role adjustments and training strategies, followed by the conclusion in Section 7, which summarizes the study's contributions and suggests directions for future research.

II. Related Work

The concept of DTs has garnered significant attention in recent years, particularly concerning their application in

enhancing industrial processes and sustainability efforts. This section reviews pertinent literature on DTs, focusing on their practical applications, the emergence of GDTs, and the associated competency frameworks and role models necessary for their successful implementation.

A. Digital Twins in Industry

DTs are virtual representations of physical assets, systems, or processes that enable real-time monitoring, simulation [1], and optimization. Grieves and Vickers (2017) define a DT as comprising three primary components: the physical entity, its digital counterpart, and the data connections that link the two [2]. In the manufacturing sector, DTs facilitate predictive maintenance, performance optimization, and lifecycle management, leading to increased efficiency and reduced operational costs. For instance, Tao et al. (2019) discuss the integration of DTs with Industrial Internet of Things (IIoT) technologies to create smart manufacturing systems that adapt dynamically to changing conditions [3].

B. Green Digital Twins for Sustainability

Building upon the traditional DT framework, Green Digital Twins (GDTs) incorporate environmental considerations to promote sustainability. GDTs aim to minimize ecological footprints by optimizing resource utilization, energy consumption, and waste management. Kritzinger et al. (2018) highlight the role of DTs in achieving sustainable manufacturing by enabling continuous environmental impact assessments and facilitating the implementation of eco-friendly practices [4]. In the beverage industry, GDTs can be employed to monitor and reduce water usage, manage energy consumption, and ensure compliance with environmental regulations, thereby supporting corporate sustainability goals. As Wagstyl et al. (2024) prove, GDTs can be used for different applications in reducing carbon emissions across various use cases in the process industry [5].

C. Competency Frameworks and Role Models for Digital Twins

The successful deployment of DTs and GDTs necessitates a well-defined competency framework and clear role delineations within organizations. Syberg et al. (2024) emphasize the importance of interdisciplinary collaboration [6]. Effective DT implementation requires expertise in areas such as data analytics, domain-specific knowledge, and information technology [7]. Beyond technical expertise, successful GDT implementation also necessitates a broader skill set encompassing methodological, social, and self-competencies. Erpenbeck et al. (2017) classify these competencies as essential elements of professional action capability, emphasizing that problem-solving skills, teamwork, adaptability, and continuous learning are critical factors in digital transformation [8]. This aligns with North and Reinhardt's (2005) findings, which underline the necessity of knowledge, ability, and motivation as key drivers for competency management in learning organizations [9].

Without these complementary skill sets, even highly technical expertise may fall short in driving the systemic changes required for sustainable and scalable GDT adoption.

III. Methodology

This study employs a mixed-methods approach [10], combining expert workshops and a structured survey to identify competency requirements for GDTs in the beverage industry. Prior to data collection, an implementation framework for GDTs was developed, outlining a structured process for integrating these digital solutions into industrial environments. This framework provided a foundation for understanding the necessary roles and competencies required to support GDT adoption. The methodology is structured into three main phases: competency identification, survey design, and data analysis.

A. Competency Identification

To establish a robust competency framework, a series of expert workshops were conducted, involving professionals with direct experience in GDT implementation in the process industry. These workshops served to refine the understanding of required skills, systematically categorizing competencies into distinct domains. Through these discussions, 49 competencies were identified and grouped into eight key categories: domain-specific knowledge (brewery operations), sustainability, data management, energy engineering, methodological skills, social competencies, and self-competencies. The structured format of the workshops ensured that all relevant aspects of competency requirements were covered, facilitating a broad and practice-oriented understanding of the necessary qualifications.

B. Survey Design

Following the workshops, a semi-structured survey was designed to quantitatively assess the perceived relevance of these competencies across four predefined roles. A carefully selected group of 15 subject matter experts, all actively engaged in GDT projects within the process industry, participated in the survey. The inclusion of only highly specialized experts ensured that responses reflected practical and domain-specific expertise. The survey was structured to evaluate the importance of each competency for the following roles:

ORCHESTRATOR: Responsible for overseeing project coordination and ensuring seamless communication between different stakeholders.
DOMAIN EXPERT (BREWERY): Ensuring the accuracy of digital representations of brewery processes and identifying optimization opportunities.
IT SPECIALIST: Managing the technological infrastructure, including software and hardware components, required for GDT implementation.
MANAGEMENT: Overseeing strategic decision-making, resource allocation, and ensuring that GDT integration aligns with corporate sustainability, digitalization and profitability objectives.

Each competency was rated using a four-point Likert scale (0 = Not relevant, 3 = Highly relevant), allowing for a nuanced assessment of perceived competency importance. Additionally, participants were encouraged to provide qualitative insights regarding potential competency gaps, role-specific challenges, and suggestions for additional roles or refinements.

C. Data Analysis

The survey responses were aggregated and analyzed to derive meaningful insights regarding competency distribution across roles. The key objectives of the analysis were to:

- Determine the extent to which the predefined roles cover the identified competencies.
- Identify competency gaps where specific roles lack necessary expertise.
- Highlight potential areas for role specialization or additional training measures.

To achieve this, mean scores were calculated for each competency. Those with an average score below 1.5 were classified as competency gaps requiring further attention. The results were visualized through heatmaps and comparative analyses to facilitate a clear interpretation of competency strengths and deficiencies within each role. Furthermore, qualitative responses were examined to contextualize quantitative findings and provide deeper insights into role-specific challenges and needs. This analysis serves as the foundation for a structured UML-Sequence Diagram that models the interactions between roles, system components, and the overall implementation process of GDTs. The implementation framework established in this study provides a systematic understanding of how different competencies interact within the organization, enabling a more refined role-component mapping for GDT deployment.

Furthermore, based on the Wagstyl (2024) model, our findings contribute to defining users and integrators of key system components such as data integration platforms, sensor networks, real-time analytics engines, and sustainability reporting tools. [5] This structured approach ensures that competency development aligns with technological requirements, allowing organizations to effectively integrate GDTs into their operations and meet sustainability objectives.

IV. Results

A. Competency Coverage and Identified Gaps

The survey results, visualized in Figure 1, illustrate the overall competency ratings across 49 identified skills within the four predefined roles: Orchestrator, Domain Expert, IT, and Management. These roles collecti

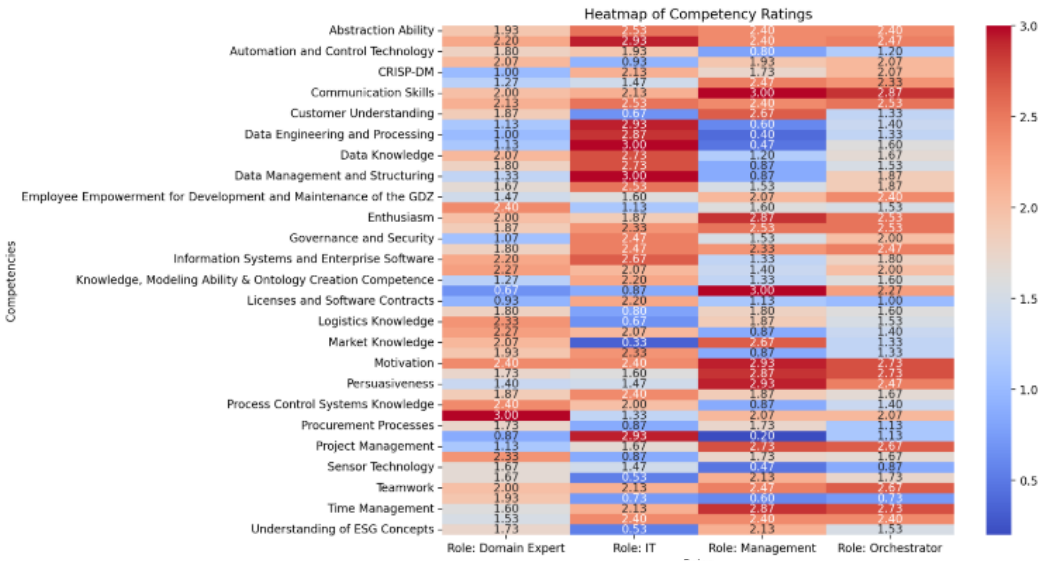

Figure 2: Heatmap of Competency Alignment by Role

such as domain knowledge, IT infrastructure, strategic management, and project coordination. For example, Domain Experts demonstrate high levels of expertise in brewery-specific processes and energy basics, while IT specialists excel in system integration and software development. Management roles stand out in strategic alignment and resource allocation, and Orchestrators are well-equipped for communication and team coordination.

However, significant competency gaps persist in specialized technical and sustainability-related areas. While roles are aligned with traditional strengths, emerging competencies crucial for GDTs, such as advanced data engineering, sensor integration, and ESG (Environmental, Social, and Governance) compliance, remain underrepresented. These gaps highlight a misalignment between the evolving requirements of GDT implementation and the existing role competencies.

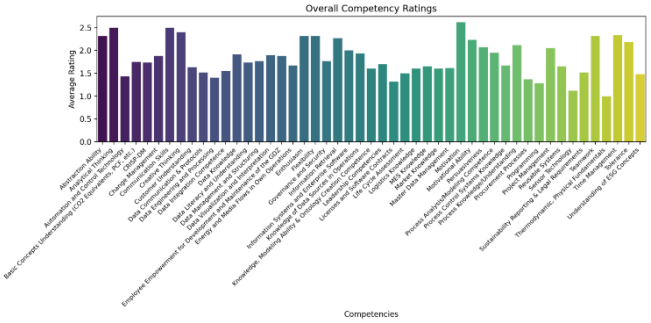

Figure 1: Average Competency Ratings Across Roles

The heatmap in Figure 2 provides a detailed visualization of how each competency aligns with the four roles. It reveals clear specialization trends, such as the strong alignment of Domain Experts with traditional brewery processes and Management with strategy and resource planning. Nevertheless, the heatmap also highlights deficiencies, particularly in areas like programming, sustainability, and advanced process optimization. These findings underscore the need for either additional roles or targeted upskilling within existing ones.

Competencies with average ratings below 1.5 were identified as critical gaps that could hinder the effective implementation of Green Digital Twins (GDTs). These are visualized in

Figure 3. The lowest-rated competencies, highlighting significant skill deficiencies across all roles, include:

- Thermodynamic and Physical Fundamentals (Rating: 1.0): Critical for modeling energy efficiency and resource optimization in production systems, yet largely underrepresented across all roles.
- Sensor Technology (1.0): Vital for real-time data acquisition and monitoring, indicating a significant lack in the ability to deploy and manage sensor systems for GDTs. Additionally, expertise in sensor placement and readings is crucial.
- Programming (1.2): A fundamental skill for developing and customizing digital twin solutions, with limited proficiency reported across the survey.
- Licenses and Software Contracts (1.3): Highlighting insufficient understanding of legal and operational frameworks for managing software ecosystems within GDT projects.
- Procurement Processes (1.3): Essential for integrating supply chain elements into GDT models, yet underdeveloped.

Beyond these top five, the survey also revealed broader deficits in competencies directly tied to energy technology and sustainability. For example:

- Data Engineering and Processing (1.4): A core competency for handling large-scale data systems essential for real-time operations and decision-making.
- Understanding ESG Concepts (1.4): Reflecting limited familiarity with environmental, social, and governance frameworks, which are critical for ensuring compliance and driving sustainability goals.
- Life Cycle Assessment (1.4): Indicating a lack of knowledge for evaluating the environmental impact of products and processes, central to holistic GDT applications.
- Data Communication and Protocols (1.4): Highlighting gaps in establishing seamless data exchange between systems.
- Sustainability Reporting and Legal Requirements (1.4): Critical for aligning organizational efforts with regulatory and stakeholder expectations.

These deficiencies underscore the need for either targeted upskilling within existing roles or the addition of new specialized roles to address technical and sustainability-related challenges effectively.

Figure 3: Competencies with Ratings Below 1.5

C. Role-Specific Competency Profiles

The competency profiles of the four predefined roles were analyzed in detail using radar charts (Figures 4–7), which provide a visual representation of strengths and weaknesses:

DOMAIN EXPERT: This role excels in brewery-specific knowledge, including process expertise and general energy principles. However, it lacks critical competencies in data engineering, programming, and ESG compliance. These gaps limit the Domain Expert's ability to adapt brewery operations to meet sustainability and digitalization goals effectively.

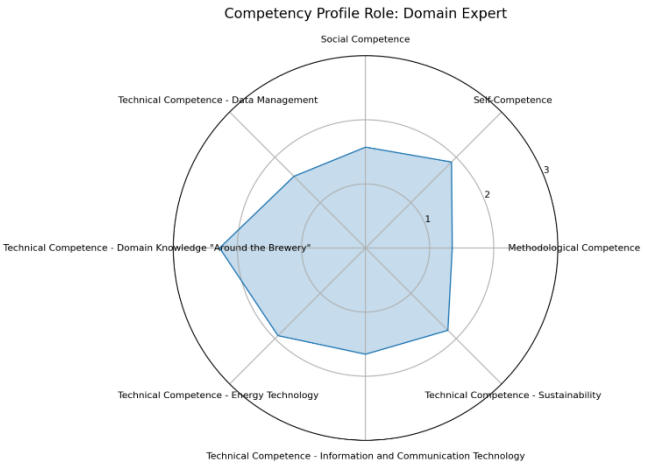

Figure 4: Radar Chart for Domain Expert

IT: The IT role demonstrates significant strength in software development, networking, and system integration. However, gaps are evident in thermodynamics, process sensor integration, and sustainability reporting. These deficiencies could hinder the IT role's contribution to developing comprehensive GDTs that integrate technical, environmental, and operational considerations.

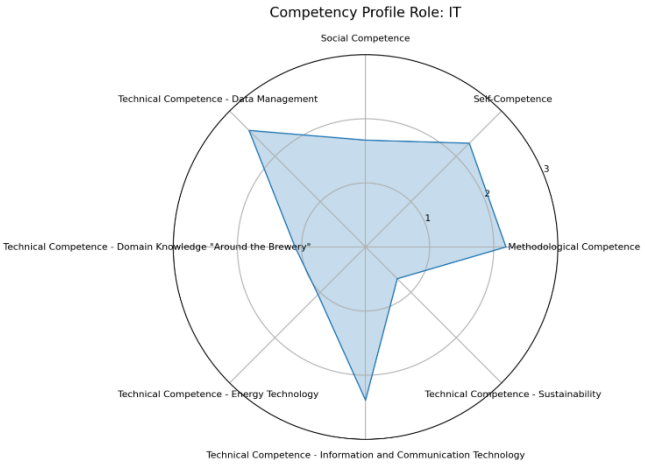

Figure 5: Radar Chart for IT Role

MANAGEMENT: Management exhibits strong capabilities in strategic planning, resource allocation, and overall alignment with organizational goals. Yet, it struggles with technical competencies such as data engineering and process-specific knowledge, as well as operational-level sustainability reporting. This disconnect could create barriers to ensuring GDT projects align with both strategic and technical goals.

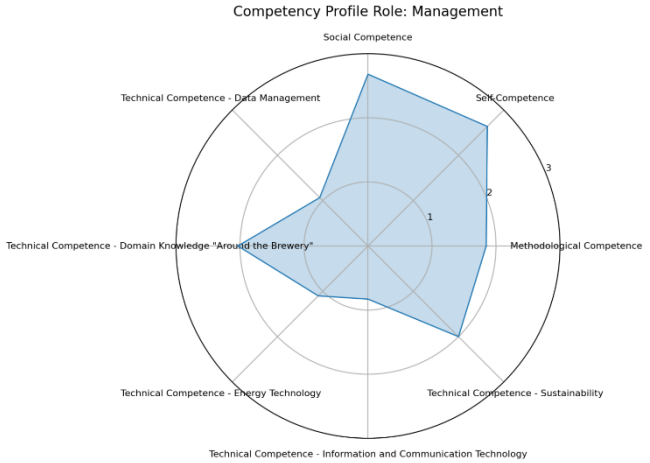

Figure 6: Radar Chart for Management Role

ORCHESTRATOR: The Orchestrator excels in project coordination, communication, and team alignment, making it a pivotal role in bridging gaps between departments. However, this role lacks sufficient technical expertise, particularly in programming, sustainability, and sensor integration. This limits its ability to translate technical innovations into actionable project outcomes.

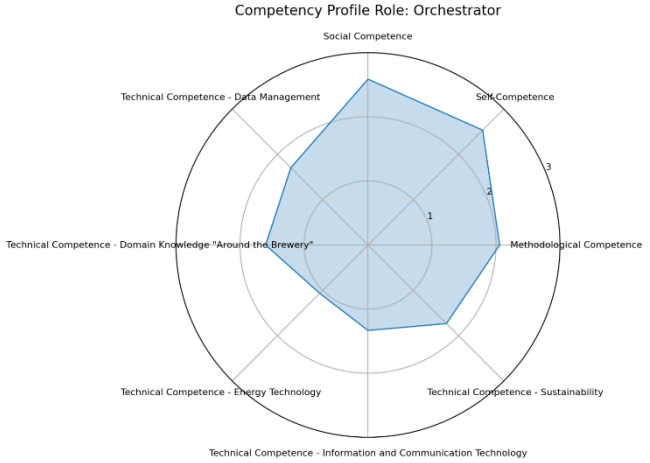

Figure 7: Radar Chart for Orchestrator Role

D. Competency Balance Across Roles

The overall competency balance across the four predefined roles—illustrated in Figure 8—indicates a generally well-distributed foundation for the implementation of Green Digital Twins (GDTs). Each role demonstrates distinct strengths aligned with its core responsibilities:

- Management excels in strategic planning, resource allocation, and high-level sustainability alignment.
- Domain Experts contribute deep knowledge of brewery processes and basic energy concepts, providing a solid foundation for GDT applications.
- Orchestrators are effective in communication, team coordination, and cross-departmental alignment, which are vital for project integration.
- IT specialists dominate in technical domains such as system integration, networking, and software development, forming the backbone for GDT implementation.

This distribution ensures that no single role is entirely redundant or overly broad in scope, enabling collaborative workflows. However, the analysis reveals that IT carries a disproportionate share of competencies critical to the technical execution of GDTs. This includes areas such as programming, data engineering, and system integration. While this alignment is expected given the technical nature of IT, the dependency on IT roles to address gaps in sustainability-related areas (e.g., ESG compliance, sensor integration) raises concerns about scalability and resilience in the long term.

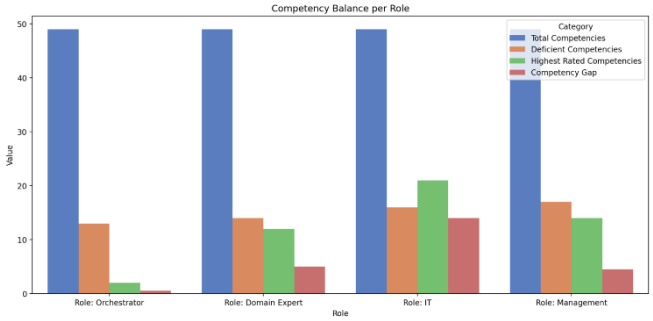

Figure 8: Competency Balance by Role

V. DISCUSSION

The findings underscore a critical misalignment between the evolving demands of GDT deployment and the competencies embedded in traditional organizational roles, we initially investigated. While the predefined roles (Orchestrator, Domain Expert, IT, Management) provide a foundational structure, they inadequately address emerging technical and sustainability requirements. Interdisciplinarity collaboration alone is insufficient without specialized competencies in data engineering and sustainability.

The significant gaps in programming and sensor integration highlight a common industry challenge: integrating IIoT with older systems, as Tao et al. [2] have noted. For example, IT professionals are proficient in software development but often lack the knowledge in thermodynamics and sensor networks that are essential for connecting physical and digital systems in GDTs. Similarly, Domain Experts frequently have a limited understanding of ESG frameworks, which makes it difficult to comply with new regulations. This issue is worsened by the absence of dedicated sustainability roles. Wagstyl et al. [4] support this observation, stating that GDTs require specific sustainability metrics that need specialized ESG governance. Additionally, relying heavily on IT roles to handle technical tasks can create scalability problems. North and Reinhardt [8] emphasize the importance of having a balanced distribution of skills to ensure that organizations remain resilient.

VI. RECOMMENDATIONS

To address these gaps, we propose augmenting the role framework with three specialized roles and targeted upskilling strategies:

DATA EXPERT:
Responsibilities: Data Engineering and Data Science, Data pipeline architecture, advanced analytics.
Rationale: Aligns with Syberg et al. [6], who advocate for dedicated data roles to manage Industrial Data Science complexity.

SUSTAINABILITY EXPERT:
Responsibilities: ESG compliance, sustainability reporting, and regulatory alignment.

Rationale: Addresses deficiencies in legal and governance competencies, ensuring adherence to frameworks like the EU Taxonomy and the global need to focus sustainable topics.

PROCESS & ENERGY TECHNOLOGY EXPERT:
Responsibilities: Sensor deployment, thermodynamic modeling, and process optimization.
Rationale: Bridges gaps in physical system integration, supporting Grieves and Vickers' [2] vision of bidirectional DT-physical interactions.

Upskilling existing roles is essential to enhance collaboration among specialized positions. For IT professionals, certifications in sensor networks (e.g., IoT protocols) and sustainability analytics are crucial. Domain Experts should engage in workshops on ESG standards and data communication protocols to deepen their understanding and integration capabilities. Management teams need training in agile sustainability strategies and lifecycle assessment tools to effectively lead and implement sustainable initiatives. These targeted upskilling efforts ensure that all roles can communicate seamlessly and work together towards the organization's sustainability goals.

VII. CONCLUSION

This study identifies critical competency gaps in GDT implementation within the beverage industry, emphasizing the insufficiency of traditional roles to meet sustainability and technical demands. By integrating roles beverage industry companies can form interdisciplinary yet specialized teams. The proposed framework not only addresses current deficiencies but also enhances scalability for further digitalisation implementations.

Future research should pilot these roles in brewery settings to validate their efficacy, leveraging Wagstyl et al.'s [5] model. Such efforts will ensure that the beverage industry remains at the forefront of sustainable digital transformation.

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