The International Journal of Advanced Manufacturing Technology (2026) 144:3327–3349
https://doi.org/10.1007/s00170-026-18083-9

ORIGINAL ARTICLE

A novel framework for analysing gamification practices and research in manufacturing

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Received: 20 December 2025 / Accepted: 2 April 2026 / Published online: 16 April 2026

Abstract

This paper introduces a structured analytical framework for examining the application of gamification in manufacturing environments, understood as the deliberate use of game-design elements to influence operators' motivation. The framework is based on a set of key dimensions that capture the functional and experiential aspects of gamified systems. Such dimensions are grouped into 5 macro-categories: context relevance, gamification design, implementation features, outcome assessment and societal impact. The framework is tested using a curated selection of selected peer-reviewed empirical studies, which allows for the identification of recurring design patterns, critical gaps, and underutilised opportunities. To further structure these insights, the paper reinterprets the MDA (Mechanics-Dynamics-Aesthetics) framework reference in the context of manufacturing, proposing design guidelines tailored to industrial applications. The analysis reveals a dominant emphasis on performance-driven mechanics, such as point systems, feedback loops, and progression, while dynamic user experiences and aesthetic engagement are less developed. In addition to the analytical contribution, this study provides practical advice for designers and practitioners looking to implement gamification in industrial settings. The framework can also be used as a reference to identify the critical aspects to consider when developing human-centred gamification strategies for manufacturing.

Keywords Gamification · Manufacturing · Work engagement · MDA framework

Abbreviations

MDA	Mechanics, Dynamics and Aesthetics
CNC	Computerized Numerical Control
MES	Manufacturing Execution System
VR	Virtual Reality
AR	Augmented Reality
PCB	Printed Circuit Board
DT	Digital Twin
HRC	Human-Robot Collaboration
SDT	Self Determination Theory

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1 Introduction

The manufacturing industry is experiencing a radical transformation, driven by the integration of digital technologies and the broader vision of Industry 4.0 [1–4]. While automation and intelligent systems are progressively reshaping production environments, the role of the human operator remains critical, especially in tasks that require adaptability, problem-solving, and flexibility [5–7]. In this complex and evolving scenario, enhancing human engagement, motivation, and performance has become an increasingly relevant challenge [8]. Gamification has emerged as a promising strategy to address this challenge [9, 10]. Gamification is defined as the use of game design elements in non-game contexts to enhance user engagement, motivation and behavioural outcomes [11]. Rooted in behavioural psychology theories, e.g. Self-Determination Theory ("SDT") and flow theory, and in user experience design, gamification leverages mechanisms such as goals, feedback, competition, and narrative to influence user behaviour and experience [12–16]. Initially developed in domains such as marketing and education [17, 18], gamification has gradually found its way into industrial contexts, where it is used to support operator training, improve task execution, reduce errors, and enhance engagement [19]. However, the application of gamification in manufacturing is still relatively new and heterogeneous. Existing studies vary widely in terms of design approaches, technological tools, implementation goals and evaluation strategies. Some interventions rely on conventional gamification elements such as points and leaderboards, while others explore more immersive or narrative-driven experiences [20]. Furthermore, gamification in manufacturing is often related to the usage of advanced technologies such as augmented reality, wearable devices or collaborative robotics, adding further layers of complexity and opportunity [19, 21]. Despite the growing number of publications and industrial experiments, a comprehensive understanding of how gamification is applied and conceptualised in manufacturing is still lacking. Building on the established definitions of gamification as the intentional use of game design elements in non-game contexts [11, 22], in industrial environments gamification is defined by more than just the presence of game-like elements, such as points, progress indicators, feedback visualisations badges and rewards; it is also defined by the deliberate use of these elements to influence the motivation, engagement and experience of operators beyond the functional execution of production tasks. From this perspective, it is important to distinguish between gamified systems and conventional digital production management tools such as KPI dashboards, monitoring interfaces and real-time feedback systems. While these tools may incorporate visual elements similar to those used in gamification, their primary purpose is informational and control-oriented. By contrast, gamified manufacturing systems introduce an explicit motivational or experiential layer in which feedback, goals and progression mechanisms are designed to influence users' engagement, behaviour and perception of work activities. This paper introduces a conceptual framework designed to analyse the use of gamification in manufacturing contexts. In this regard, the authors define gamification in manufacturing as the intentional integration of game-design elements such as explicit goals, rules, feedback, points, challenges, progress tracking, storytelling and rewards into work-related systems to shape manufacturing operators' motivation and behaviour. Accordingly, systems that only display performance indicators or support monitoring and control, without such motivational game-like features, should not be considered gamified. The proposed framework is based on a set of analytical dimensions that capture important aspects of gamification implementation. The paper demonstrates how this structure can support a deeper understanding of gamified interventions, highlights design trade-offs, and guides the more informed development and evaluation of future implementations. Specifically, this paper aims at answering the following research question: *What are the key dimensions that can guide process designers into the practical development of effective gamification strategies in manufacturing environments?* The paper is organised as follows: Sect. 2 summarises the literature review analysis while Sect. 3 highlights the methodology implemented to define the analytical framework, while related results are shown in Sect. 4. Finally, Sect. 5 discusses main practical implications and summarises the main conclusions.

2 Literature review

To investigate how gamification has been applied in manufacturing contexts, a literature search was conducted using the Scopus database.

2.1 Data collection

The search was designed to collect a broad yet relevant body of literature by including multiple terms related to gamification and manufacturing. The following query was used: *"TITLE-ABS-KEY (("gamification" OR "game-based learning" OR "serious games" OR "playful design" OR "game mechanics" OR "gameful design" OR "game" OR "game design") AND ("manufacturing" OR "production")) AND PUBYEAR > 2014 AND PUBYEAR < 2026 AND (LIMIT-TO (SUBJAREA, "ENGI")) AND (LIMIT-TO (LANGUAGE, "English")).* This query returned a total of 3,558 documents published between 2015 and 2025. The inclusion of broad terms such as "game" and "production" in the search string resulted in a high number of unrelated results. In order to refine the corpus, a first stage of screening based on titles and abstracts was carried out. At this stage, all studies that were clearly unrelated to the application of game-like logic in industrial or production environments were excluded. This filtering step reduced the sample to 67 potentially relevant studies, grouped into three broad application areas: manufacturing (76%), supply chain & logistics (13%) and education (11%):

- The manufacturing category includes studies where game elements are applied directly within production environments, e.g., assembly lines, quality control, maintenance operations, etc [21].

Table 1 Summary of the inclusion criteria adopted

Criterion	Inclusion
Language	English
Publication year	2015–2025
Subject area	Engineering
Content relevance	Include gamification or game elements in manufacturing or production
Conceptual focus	Focus on gamification (not game theory)
Application domain	Application within real or simulated industrial/production environments

- The education category refers to work that focuses on the use of games to teach manufacturing-related topics, typically within an academic environment [23, 24].
- The supply chain and logistics category includes articles related to warehouse operations, transportation and supply network management [25, 26].

A second screening was then carried out to assess whether the selected papers described the use of gamification principles to support activities in manufacturing or production environments. At this stage, studies that merely used the word "game" but referred to game theory rather than gamification were excluded. It is important to clarify that game theory refers to mathematical models of strategic interaction between rational agents, whereas gamification refers to the experiential and motivational aspects of user engagement through game-like dynamics [27–32]. The exclusion of game theory papers resulted in a refined pool of 36 articles that explicitly addressed gamification in industrial contexts. A third exclusion step was applied to filter out contributions from the field of supply chain and logistics and from the field of engineering education. This process resulted in a set of 29 core articles. To supplement the initial search and to avoid missing key contributions, a snowballing strategy was applied, involving both backward and forward citation tracking of the 29 selected papers. This iterative process led to the identification and inclusion of 3 additional relevant studies that were not identified in the original database search. The final pool consisted of 32 peer-reviewed articles, which formed the basis of the subsequent analysis. Table 1 shows respectively the exclusion/inclusion criteria adopted while Fig. 1 shows the procedure implemented.

2.2 Overview of gamification in manufacturing

The final set (32 papers) analysed in this review consists of 17 journal articles, 13 conference papers and 1 book published between 2015 and 2025. All included papers explicitly address the application of gamification in industrial or

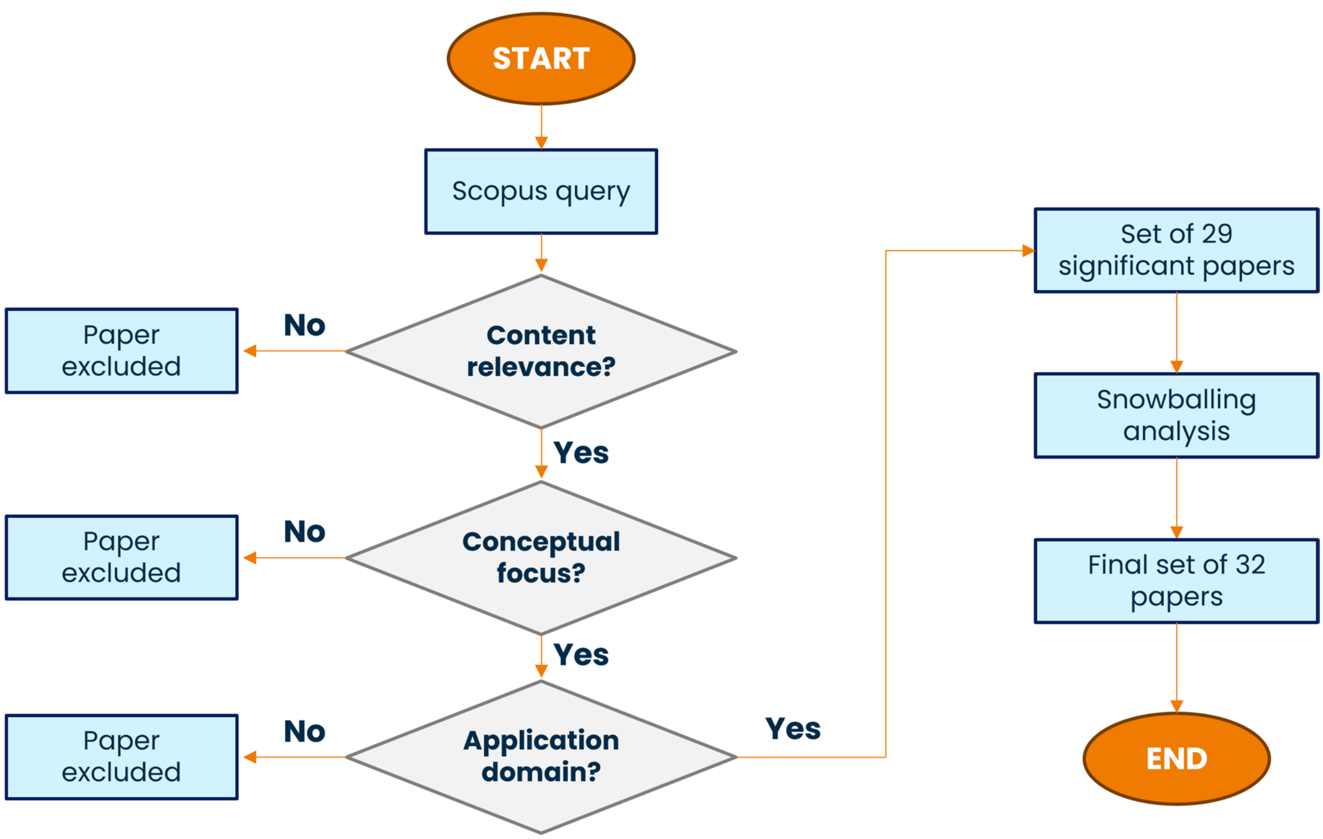

Fig. 1 Flowchart of the literature review procedure

production-related contexts. They cover different industrial domains (e.g. discrete assembly, maintenance, quality control, logistics), gamification strategies (e.g. conventional vs. narrative) and technological implementations (e.g. augmented reality, mobile platforms, collaborative robotics). In addition, the studies vary in their experimental designs, evaluation metrics, and intended outcomes. A complete list of the 32 articles reviewed, along with key data and classification variables, is provided in Table 2. Journals range from manufacturing and industrial engineering to human-computer interaction and behavioural sciences, reflecting the cross-disciplinary nature of the topic. A few conference proceedings also contribute, suggesting that some of the research is still exploratory and often presented in early-stage academic forums.

In manufacturing, gamification is still in its infancy, and it has been applied exploratively in few fields. The selected studies were organized according to their primary application domains within manufacturing. Specifically, in this section the literature was classified into four categories:

- **t**he assembly process, comprising studies in which gamification is embedded directly within assembly operations.
- operator training, including contributions aimed at improving the learning and training experiences of operators.
- industrial human-robot collaboration, where gamification is employed to facilitate interaction between human workers and robotic systems.
- other manufacturing applications, covering heterogeneous applications that do not clearly fall within the previous domains.

2.2.1 Assembly process

Regarding the assembly field, Dolly et al. [34] presented a novel empirical study demonstrating that gamification can be a powerful tool for improving both operational efficiency and human factors in manufacturing assembly. The contribution of this work lies in bridging traditional manufacturing performance metrics with cognitive considerations: it systematically evaluates a gamified assembly task and measures not only production outcomes (e.g. productivity), but also psychological workload and worker engagement. Agati et al. [35] presented GRAAL, an innovative system that combines augmented reality (AR) with gamification to assist operators in manual PCB (i.e., printed circuit boards) assembly. The system provides step-by-step AR visual guidance to reduce cognitive load and incorporates gamified elements to combat task repetition and demotivation. This study makes a significant contribution to the literature by demonstrating the feasibility and effectiveness of human-centred gamified AR systems in manufacturing. Ulmer et al. [38] presented a novel manufacturing assistance system that dynamically adapts to individual worker capabilities by combining hardware modularity with gamification. The core contribution of this work is a human factors-aware framework for manual assembly: the system can adapt assistance hardware modules and tailor content to a worker's cognitive and physical needs. Ohlig et al. [39, 53] conducted an extensive empirical study to evaluate how gamified performance metrics affect worker performance and motivation in a manual assembly context. In this human-centred approach to performance management, a conventional Manufacturing Execution System (MES) was augmented with standard gamification strategies. The contribution of this study is the empirical evidence it provides: the gamified KPI dashboard significantly improved operator motivation and even operational performance compared to non-gamified conditions. Seo et al. [20] explored the conditions under which gamification effectively motivates manufacturing workers, focusing on the role of narrative elements in encouraging self-directed behaviour change. The contribution lies in highlighting that, beyond simply adding points or badges, embedding a compelling storyline or thematic context can enhance intrinsic motivation and encourage workers to voluntarily adopt positive practices. Ulmer et al. [52] proposed a human-centred gamification framework tailored for manufacturing, designed to engage and upskill workers performing manual tasks. Korn et al. [60] examines the potential integration of gamification into automotive production workflows, with a particular focus on how such approaches are perceived and accepted by industry practitioners. Lee et al. [61] applied a structured design framework to gamify a repetitive bolt-tightening task on an automotive assembly line. This study shows how a well-designed gamification framework can transform routine manufacturing tasks into more playful and motivating experiences for employees. In a different work, Roh et al. [62] also investigated how the introduction of game-like goals and feedback into a bolt-tightening task can increase the intrinsic motivation of assembly line workers. The results suggest that the gamified condition improved workers' flow states and positive emotions during the task, validating gamification to mitigate the demotivating effects of repetitive industrial work.

2.2.2 Operator training

Another common benefit of applying gamification in industrial tasks is within operator's training session. Santos et al. [45] proposed a unified framework for industrial training that combines virtual reality (VR), augmented reality (AR), and gamification into a single, configurable system.

Table 2 Final set of papers in scope

Year	Authors	Reference	Title	Document type	Source title
2025	Capponi et al., 2025	[33]	Gamification in manufacturing: some insights in human–robot collaboration assembly and preliminary results	Article	International Journal of Advanced Manufacturing Technology
2024	Dolly et al., 2024	[34]	The effects of gamification for manufacturing (GfM) on workers and production in industrial assembly	Article	Robotics and Computer-Integrated Manufacturing
2024	Agati et al., 2024	[35]	GRAAL—modeling, prototyping and assessing a gamified responsible augmented assembly line system	Article	International Journal of Advanced Manufacturing Technology
2024	Konzack, 2024	[36]	Gamification and Industry 4.0: Gamified Smart Manufacturing	Book	Gamification and Industry 4.0: Gamified Smart Manufacturing
2024	Capponi, Culotta, et al., 2024	[37]	Enhancing manufacturing quality through gamification: an exploratory study in collaborative assembly process	Conference paper	International Conference on Quality Engineering and Management
2023	Ulmer et al., 2023	[38]	A human factors-aware assistance system in manufacturing based on gamification and hardware modularisation	Article	International Journal of Production Research
2023	Ohlig et al., 2023	[39]	Human-centered performance management in manual assembly–The impact of gamified KPI provision on performance and motivation	Article	International Journal of Computer Integrated Manufacturing
2023	Leite et al., 2023	[40]	How Has Gamification in the Production Sector Been Developed in the Manufacturing and Construction Workplaces?	Article	Buildings
2023	Venås et al., 2024	[41]	Exploring human-robot cooperation with gamified user training: a user study on cooperative lifting	Article	Frontiers in Robotics and AI
2023	Zhu et al., 2023	[42]	Digital Twin-based shop-floor scheduling service gamification	Conference paper	Procedia CIRP
2022	Keepers, Nesbit, Romero, et al., 2022	[21]	Current state of research & outlook of gamification for manufacturing	Article	Journal of Manufacturing Systems
2022	Spahrbier et al., 2022	[43]	Supporting human monitoring activities in highly automated manufacturing through gamification	Article	Computers and Industrial Engineering
2022	Ulmer et al., 2022a	[44]	Gamification of virtual reality assembly training: Effects of a combined point and level system on motivation and training results	Article	International Journal of Human Computer Studies
2022	Santos et al., 2022	[45]	Generic XR game-based approach for industrial training	Conference paper	ICGI 2022 - International Conference on Graphics and Interaction, Proceedings
2022	Ulmer et al., 2022b	[46]	Usage of digital twins for gamification applications in manufacturing	Conference paper	Procedia CIRP
2021	Dewald et al., 2021	[47]	Using gamification on the shop floor for process optimization in machining production	Article	MM Science Journal
2021	Krath et al., 2021	[48]	Revealing the theoretical basis of gamification: A systematic review and analysis of theory in research on gamification, serious games and game-based learning	Article	Computers in Human Behavior
2021	Seo et al., 2021	[20]	Goldilocks conditions for workplace gamification: how narrative persuasion helps manufacturing workers create self-directed behaviors	Article	Human-Computer Interaction
2020	Reis et al., 2020	[49]	Prospects for using gamification in industry 4.0	Article	Production
2020	Warmelink et al., 2020	[50]	Gamification of production and logistics operations: Status quo and future directions	Article	Journal of Business Research
2020	Ulmer et al., 2020a	[51]	Gamified Virtual Reality Training Environment for the Manufacturing Industry	Conference paper	Proceedings of the 2020 19th International Conference on Mechatronics - Mechatronika, ME 2020
2020	Ulmer et al., 2020b	[52]	Human-centered gamification framework for manufacturing systems	Conference paper	Procedia CIRP
2020	Ohlig et al., 2021	[53]	Human-centered performance management in manual assembly	Conference paper	Procedia CIRP

Table 2 (continued)

Year	Authors	Reference	Title	Document type	Source title
2019	Deif and Stadnicka, 2019	[54]	A gamification approach application to facilitate lean manufacturing knowledge acquisition	Article	Management and Production Engineering Review
2019	Alavesa et al., 2019	[55]	Context defined aspects of gamification for factory floor	Conference paper	2019 11th International Conference on Virtual Worlds and Games for Serious Applications, VS-Games 2019 - Proceedings
2018	Liu et al., 2018	[56]	Gamification's impact on manufacturing: Enhancing job motivation, satisfaction and operational performance with smartphone-based gamified job design	Article	Human Factors and Ergonomics In Manufacturing
2018	Warmelink et al., 2018	[57]	Gamification of the work floor: A literature review of gamifying production and logistics operations	Conference paper	Proceedings of the Annual Hawaii International Conference on System Sciences
2017	Matsas and Vosniakos, 2017	[58]	Design of a virtual reality training system for human–robot collaboration in manufacturing tasks	Article	International Journal on Interactive Design and Manufacturing
2017	Schuldt and Friedemann, 2017	[59]	The challenges of gamification in the age of Industry 4.0: Focusing on man in future machine-driven working environments	Conference paper	IEEE Global Engineering Education Conference, EDUCON
2017	Korn et al., 2017	[60]	Gamification of production? A study on the acceptance of gamified work processes in the automotive industry	Conference paper	Advances in Intelligent Systems and Computing
2016	Lee et al., 2016	[61]	A case study in an automotive assembly line: Exploring the design framework for manufacturing gamification	Conference paper	Advances in Intelligent Systems and Computing
2016	Roh et al., 2016	[62]	Goal-based manufacturing gamification: Bolt tightening work redesign in the automotive assembly line	Conference paper	Advances in Intelligent Systems and Computing

The authors contribute a generic training design methodology capable of evolving with changing processes and tools, addressing a key gap in earlier AR/VR training solutions that were often scenario specific. Ulmer et al. [46] provided empirical evidence on the impact of gamification within a virtual reality assembly training context. By comparing a VR training modality that incorporated standard gamification elements (a point-based scoring and level progression system) with an equivalent non-gamified VR training programme, the authors demonstrated that gamification can significantly improve real-world performance outcomes. Trainees who experienced the gamified VR training made fewer errors and required less assistance when performing the actual assembly, highlighting the value of gamification in skill transfer. Ulmer et al. [46] also explored how digital twin technology can enhance gamification in manufacturing environments. The authors provided a comprehensive overview of digital twin approaches and how they can be integrated with gamified support and training systems. Deif and Stadnicka [54] evaluated the use of gamification as a training method to improve employees' understanding of lean manufacturing principles. The proposed gamification approach combined narrative elements (immersive, hands-on problem scenarios) with standard game mechanics to create a realistic learning experience, demonstrating that gamified learning can significantly boost knowledge acquisition and enhance operators' motivation.

2.2.3 Industrial human-robot collaboration

Recently, the application of gamified interfaces has emerged in assembly processes characterised by human-robot collaboration. Capponi et al. [33, 37] investigated the integration of gamification into a human-robot collaborative assembly environment to improve operational quality and engagement on the shop floor. Venås et al. [41] applied gamification to human-robot collaboration training, underlining that a game-based approach can accelerate skill acquisition for a cooperative lifting task. The authors showed that a wide range of workers quickly achieved proficiency in the task after a short, gamified training programme. More sophisticated technologies are implemented by Matsas and Vosniakos [58] who presented an immersive virtual reality training system aimed at improving safety and cooperation in human-robot manufacturing tasks. Designed as a serious game, the VR system allows trainees to practice cooperative operations in a risk-free virtual environment, thereby training users to react appropriately and develop a heightened awareness of the robot's movements.

2.2.4 Other manufacturing applications

Finally, the other articles cover more diverse topics in manufacturing, such as machining, scheduling and process automation. For example, Dewald et al. [47] used gamification as an innovative way to engage shop-floor workers in continuous process improvement in machining production. By introducing standard gamification principles, this paper suggests that workers can be more actively engaged in identifying and implementing improvements in their daily tasks. Liu et al. [56] provided strong empirical evidence of the benefits of gamified job design in a manufacturing environment, using a smartphone-based platform. By gamifying the operation of CNC machines, the authors demonstrated significant increases in worker motivation, job satisfaction and productivity. Zhu et al. [42] presented a gamified shop floor scheduling system that uses a digital twin of the production shop floor to improve the efficiency and user experience of schedulers. The novel contribution lies in the extension of gamification to manufacturing scheduling activities by combining game mechanics (points, badges, leaderboards) and a narrative context. The system's integration with real-time digital twin data provides immediate visual feedback on scheduling outcomes, engaging the user's sense of sight through a dynamic interface. Finally, Spahrbier et al. [43] applied gamification to the monitoring of automated production processes, with the aim of improving the operator experience during a typically monotonous task. The authors integrated gaming elements into a control room dashboard and found that operators reported significantly higher levels of enjoyment, better satisfaction of psychological needs (competence and autonomy), and an improved overall user experience.

In summary, implementing gamification in the manufacturing sector holds great promise for improving productivity and employee engagement. However, the success of such initiatives depends heavily on two critical factors: employee adoption and sustainability of engagement. In traditional manufacturing environments, employees may perceive gamified systems as unnecessary or overly complex, leading to resistance. In addition, to maintain long-term engagement, gamified elements need to be continually updated and refreshed to prevent disengagement over long time.

3 Methodology

This study provides an analytical framework that was developed to systematically classify and interpret empirical research on gamification in manufacturing. This framework was designed to be used as an analysis tool for characterising the adoption of gamification principles in manufacturing contexts. It distinguishes between systems that incorporate isolated game-like elements and those that leverage gamification intentionally as a motivational design strategy. This framework was created through a multi-stage process that combined expert consultation with literature-driven refinement. In the first stage, informal focus groups were conducted with academic researchers and experts in industrial engineering, human-centred manufacturing and gamification design. The aim of these discussions was to identify the core conceptual areas that should guide the analysis of gamified interventions in manufacturing. As a result, five high-level macro-categories were identified:

- Context relevance: It captures the industrial setting in which gamification is applied, as well as the practical importance of the problem it aims to address.
- Gamification design: This refers to the structural and conceptual features of the gamified system, including how it is designed to engage users.
- Implementation features: This concerns the technological and operational aspects of how the gamification is delivered and integrated into work processes.
- Outcome assessment: Focuses on how the effectiveness of the gamification is assessed, and on the results observed or reported.
- Societal impact: Encompasses the study's consideration of ethical issues and user well-being. It is a transversal macro-category and encompasses ethical considerations that arise during the design, implementation, evaluation and contextualisation of gamified systems.

These macro-categories reflect the dimensions that are essential for understanding where and why gamification is applied, how it can be designed and implemented, how it can be evaluated, and the extent to which human factors and social implications are considered. In the second phase, each macro-category was broken down into specific analytical dimensions, derived from the literature and iteratively refined based on recurring features observed across studies (see Fig. 2).

This two-level framework enables a structured, multi-dimensional classification of each study, supporting comparative insights and the identification of research gaps. The complete set of macro-categories, their corresponding analytical dimensions and definitions are illustrated in Table 3.

4 Results

The selected empirical studies were classified using the proposed analytical framework. This structured analysis allows for a thorough comparison of the single contributions, revealing trends and areas of under-explored potential. The following sections present the classification of the analysed papers. The sample of articles analysed in the following sections is smaller than that provided in Table 2 as a subset of these papers can be classified as review or state-of-the-art

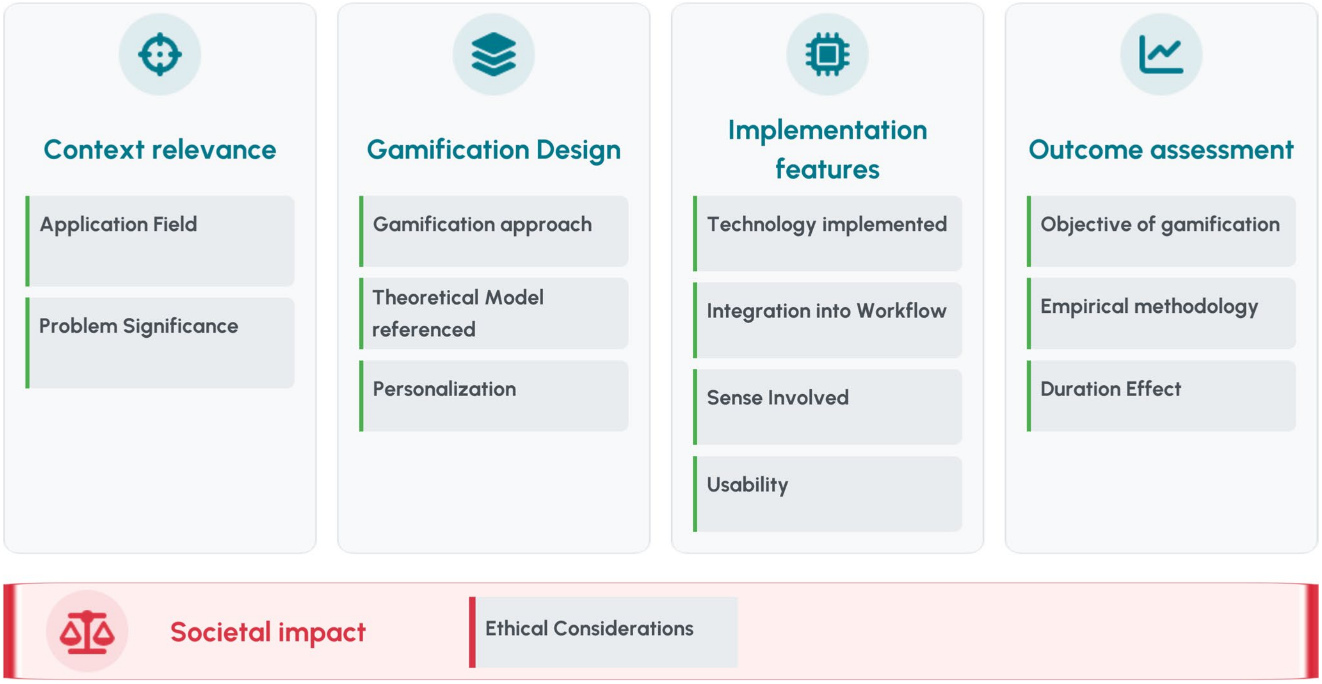

Fig. 2 Gamification analytical framework

studies. These papers aim to define the boundaries, challenges and emerging trends of gamification, propose conceptual frameworks or systematise the current state of research. Although not tied to a specific use case, such studies provide the theoretical basic that supports applied research. Examples include systematic literature reviews, theoretical discussions and conceptual frameworks that outline how gamification can be implemented into manufacturing. A brief overview of the excluded papers is reported below. For example, Konzack et al. [36] presented a conceptual investigation of the interplay between gamification and Industry 4.0, highlighting the need to combine motivational psychology, game design and industrial production knowledge to develop more effective gamified systems. Leite et al. [40] conducted a systematic literature review focusing on the adoption of gamification in manufacturing and construction workplaces, highlighting critical gaps such as the lack of ethical discussion and the limited presence of gamification in the construction sector. Keepers et al. [21] provided an analysis on the current status and future prospects of gamification for manufacturing, suggesting strategic directions and highlighting the lack of large-scale applications beyond academic settings. Krath et al. [48] reviewed over one hundred studies to uncover the psychological theories that drive gamification, serious games and game-based learning. Similarly, Reis et al. [49] identified eleven practical considerations for using gamification in industrial contexts and outline five specific use cases, providing concrete guidance for practitioners. Warmelink et al. [50, 57] synthesised the literature on gamification of production and logistics operations, reporting that most studies are based on design research and use elements such as points, achievements and metaphorical representations. Alavesa et al. [55] investigated how context shapes the effectiveness of gamification in factory environments through a combination of literature analysis and qualitative interviews, emphasising the need to adapt solutions to specific operational settings. Finally, Schuldt and Friedemann [59] reflected on the human dimension of gamification in Industry 4.0, highlighting the importance of employee involvement and outlining challenges such as technological acceptance and behavioural resistance.

4.1 Context relevance

Gamification in manufacturing is being applied in a variety of fields, but a closer examination of the literature reveals that certain areas are attracting more attention than others. In this regard the macro-dimension “context relevance” was introduced. Such dimension can be further broken down into application field and problem significance. In detail:

- Application field refers to the specific manufacturing domain where gamification is applied, and four main application areas emerge consistently across the studies reviewed:

Table 3 Macro-categories and analytical dimensions of the framework used to assess gamification in manufacturing applications

Macro-Category	Analytical Dimension	Definition
Context Relevance	Application Field	The operational domain in which gamification is applied (e.g., assembly, training, logistics).
	Problem Significance	The nature and importance of the addressed issue (e.g., productivity, safety, quality, motivation).
Gamification Design	Gamification approach	The style of gamification used, such as conventional (points, badges) or narrative-driven approaches.
	Theoretical model referenced	Whether the design references established frameworks (e.g., SDT, MDA, Octalysis).
	Personalization	The extent to which the gamified system is adapted to individual users or roles.
Implementation features	Technology implemented	The technologies supporting the system (e.g., tablets, VR, sensors, wearables).
	Integration into workflow	The degree to which gamification is embedded in actual production workflows
	Sense involved	The feedback modalities employed (e.g., visual, auditory, haptic).
	Usability	The perceived ease of use, intuitiveness, and user-friendliness of the system.
Outcome assessment	Objective of gamification	The aim of the implementation of gamified systems (improve performance, quality, training, etc.)
	Empirical Methodology	The type of evaluation used (experiments, observational studies).
	Duration effect	Whether outcomes are measured only in the short term or also tracked over longer periods.
Societal impact	Ethical Considerations	Ethical concerns derived from the integration of gamification in manufacturing

1. Assembly operations are one of the most frequently gamified areas.
2. A second area where gamification is gaining attention is in human-robot collaboration. In collaborative workspaces humans and robots work together sharing spaces and goals and gamified systems can enhance communication and interaction [6, 63, 64].
3. Operator training is another key application area. Here, gamification is not used to support real-time production, but as part of structured learning environments, especially during onboarding or upskilling programmes.
4. Machining and process optimisation represents a smaller but significant field of application of gamification in manufacturing.

- Problem significance captures the nature and importance of the challenge that gamification is designed to address. It distinguishes between:

1. Interventions that target core industrial priorities, such as improving productivity, ensuring product quality or enhancing workplace safety.
2. Interventions that support human factors, including skill development, managing and sustaining motivation.

This classification enables to assess not only where gamification is applied, but also why it is considered valuable in that context.

Table 4 presents the selected articles analysed through the lens of context relevance analytical dimensions.

Most studies focus on production-floor tasks that are central to manufacturing operations. Assembly operations are the context that is addressed most frequently, reflecting the repetitive and labour-intensive nature of assembly work and its susceptibility to operator disengagement. Many interventions aim to improve performance or quality in assembly tasks, indicating their high practical significance for productivity. A significant proportion of papers deals with operator training, including onboarding and upskilling in simulated or controlled settings, which highlights the importance of preparing workers for increasingly complex manufacturing roles. A few studies address human-robot collaboration (HRC) scenarios, which are an increasingly important context in modern factories due to the significant safety and trust issues involved, especially when worker safety is at stake. There are also instances of gamification being applied to planning and monitoring tasks, such as scheduling and

Table 4 Articles in scope analysed through context relevance dimensions

Authors	Application field	Problem significance
Capponi et al., 2025	HRC	Improve HRC assembly productivity and quality
Dolly et al., 2024	Assembly	Improves assembly task productivity
Agati et al., 2024	Assembly	Targets performance in assembly
Capponi et al., 2024	HRC assembly	Improves HRC process quality and engagement
Ulmer et al., 2023	Assembly	Focuses on productivity in manual assembly
Ohlig et al., 2023	Assembly	Addresses efficiency in assembly operations
Venås et al., 2024	HRC	Develops skills for human–robot teamwork
Zhu et al., 2023	Scheduling	Optimizes scheduling efficiency
Spahrbier et al., 2022	Automation	Enhances operator engagement in monitoring
Ulmer et al., 2022a	Assembly/training	Trains assembly operators
Santos et al., 2022	Training	Upskills workers
Ulmer et al., 2022b	Training	Provides workforce training
Dewald et al., 2021	Machining	Engages workers in process optimization
Seo et al. 2021	Assembly	Improves assembly work motivation and performance
Ulmer et al., 2020a	Training	Prepares operators via training
Ulmer et al., 2020b	Assembly	Supports assembly tasks
Ohlig et al., 2021	Assembly	Aims at productivity in assembly
Stadnicka & Deif, 2019	Training	Provides training in production concepts
Liu et al., 2018	Machining	Increases CNC operation performance
Matsas & Vosniakos, 2017	HRC	Promotes workplace safety in HRC
Korn et al., 2017	Assembly	Improves assembly work processes
Lee et al., 2016	Assembly	Enhances assembly task engagement/performance
Roh et al., 2016	Assembly	Boosts motivation in assembly line work

monitoring automated processes. The importance of these issues addressed generally aligns with the context: interventions aimed at core production activities or safety-critical training are generally considered to be of great importance. Overall, the literature indicates that gamification is being applied where there is clear relevance to operational efficiency, workforce development or safety.

4.2 Gamification design

Gamification design focuses on the conceptual structure of the gamified system. This includes the type of gamification approach used, such as standard or narrative, whether there is a theoretical foundation, the level of personalisation of the gamified experience. In detail they are:

- Gamification approach: in literature two primary paradigms can be identified: standard gamification and narrative gamification [20]:
-
    1. The term standard or conventional gamification often relates to images of points, levels, badges, leaderboards, etc. These mechanics are used to stimulate behaviour, reinforce actions and visualise performance and its motivational power is typically extrinsic, relying on competition, rewards and reinforcement loops.
    2. The narrative gamification builds engagement through the principles of storytelling and role-playing such as: character-driven missions and quests, immersive settings or metaphors, avatars and personalised roles. This form of gamification prioritises intrinsic motivation, emotional involvement and a sense of purpose.

- Theoretical model referenced captures whether the design of the gamified intervention is explicitly based on established theoretical models or motivational frameworks. These may include:
-
    1. The Octalysis Framework that identifies eight core human motivators in gamified experiences [13];
    2. The Mechanics-Dynamics-Aesthetics (MDA) framework that is a formal model for analysing the structure and player experience of game systems [14];
    3. Keepers' classification which identifies a set of gaming elements that can be applied to manufacturing [65];
    4. "5W2H + M" framework that introduced 7 dimensions that must be addressed to guide the gamification design process in order to enhance motivation [66];

5. Mixed that includes all those article whose gamification design is inspired by several gamification theories.

- Personalization assesses how the gamified system adapts to individual users. This may involve features such as performance-based adaptation, user-specific feedback, role-based game paths or customisable elements. In the classification, systems will be noted as follows:

1. Uniform experience that refers to a gamified system presenting the same content, mechanics and feedback to all users without differentiating or tailoring it based on characteristics, performance or preferences.
2. Static tiered progression where all users advance through a predefined sequence of levels or stages of increasing difficulty or complexity. Although this introduces variation over time, the progression path remains fixed and identical for all users.
3. Adaptive personalisation where the game's elements, difficulty and content are dynamically adjusted based on the individual user's behaviour, performance or profile, offering a tailored and responsive experience.

Table 5 presents the selected articles analysed through the lens of gamification design analytical dimensions.

The predominant design paradigm across the studies is "standard" gamification, i.e. the use of points, badges, leaderboards, immediate feedback and other game mechanics, without an overarching story or fantasy context. As shown in Table 5, only a few studies incorporate significant narrative elements, and even these typically combine narrative with standard mechanics (a hybrid approach) rather than using narrative alone. In practical terms, many manufacturing gamification applications opt for straightforward extrinsic motivators (scores, levels, competitions) to drive behaviour, likely due to their simplicity and ease of integration into workflow. For example, Capponi et al. [37] explicitly avoided any storyline in their human-robot assembly game, relying purely on real-time performance feedback. In a following study, the same authors also tried to include narrative elements into HRC assembly processes [33]. Similarly, the few hybrid designs introduce thematic contexts or role-play alongside points and challenges [42, 54]. Notably, few studies refer explicitly to a specific, well-defined gamification design framework. In most cases, the design approach appears to be mixed, combining elements from multiple models without clearly basing the implementation on a single theoretical reference. Finally, it is evident from Table 5 that adaptive personalisation is extremely rare across the reviewed studies, with only two attempts identified to move towards real-time tailoring of the gamified experience. This highlights a clear gap in the literature. Many implementations still rely on uniform designs or static tiered progression, whereby all users are exposed to the same game elements or pre-defined level structures, regardless of their individual characteristics or performance.

To deeper analyse the application of gamification in manufacturing, the articles in scope were analysed using the Mechanics-Dynamics-Aesthetics (MDA) framework introduced by Hunicke, LeBlanc and Zubek [14]. The MDA framework, which is widely recognised in game design and research [67, 68], supports the systematic decomposition of game systems into three interrelated dimensions: (i) Mechanics, which are the underlying rules and features; (ii) Dynamics, which represent the behaviour that results from user interaction with these mechanics; and (iii) Aesthetics, which describe the emotional experiences triggered during gameplay [14, 69–71]. Using the MDA framework allows for a comparative analysis of which aspects of gamification are most emphasised in this domain and how they contribute to practical outcomes such as productivity, engagement or learning. Each dimension of the MDA model can be broken down into the following elements [69, 70].

For the mechanics dimension, which refers to the components and rules implemented by the system, the main elements are:

- Points/scoring systems refer to numerical metrics used to measure performance and incentivize behaviour.
- Levels/Progression/Award refer to hierarchical structures that organise user progression and provide increasing levels of challenge.
- Feedback systems refer to real-time responses from the system that signal success, failure, or required actions, often through audiovisual or textual cues.
- Time constraints/resource scarcity refer to limitations in available time, energy, or other resources that create strategic tension and encourage efficient behaviour.

For the dynamics dimension, which include the emergent patterns of behaviour that result from user interaction with the mechanics, the main elements include:

- Challenge refers to the level of difficulty presented by the system that requires users to exert effort and skill to succeed.

Table 5 Articles in scope analysed through gamification design analytical dimensions

Authors	Gamification approach	Theoretical model referenced	Personalization
Capponi et al., 2025	Standard/Narrative	Octalysis/MDA framework	Static tiered progression
Dolly et al., 2024	Standard	Keepers' classification	Static tiered progression
Agati et al., 2024	Standard/Narrative	5W2H + M framework	Adaptive personalisation
Capponi et al., 2024	Standard	Octalysis framework	Static tiered progression
Ulmer et al., 2023	Standard	Mixed	Static tiered progression
Ohlig et al., 2023	Standard	Mixed	Uniform experience
Venås et al., 2024	Standard	Mixed	Uniform experience
Zhu et al., 2023	Standard/Narrative	Mixed	Static tiered progression
Spahrbier et al., 2022	Standard/Narrative	Mixed	Static tiered progression
Ulmer et al., 2022a	Standard/Narrative	Mixed	Static tiered progression
Santos et al., 2022	Standard/Narrative	Mixed	Uniform experience
Ulmer et al., 2022b	Standard/Narrative	Mixed	Adaptive personalisation
Dewald et al., 2021	Standard	Mixed	Uniform experience
Seo et al. 2021	Standard/Narrative	Mixed	Uniform experience
Ulmer et al., 2020a	Standard	Mixed	Uniform experience
Ulmer et al., 2020b	Standard	Mixed	Uniform experience
Ohlig et al., 2021	Standard	Mixed	Uniform experience
Stadnicka & Deif, 2019	Standard/Narrative	Mixed	Uniform experience
Liu et al., 2018	Standard	Mixed	Uniform experience
Matsas & Vosniakos, 2017	Standard	Mixed	Uniform experience
Korn et al., 2017	Standard	Mixed	Uniform experience
Lee et al., 2016	Standard	Mixed	Uniform experience
Roh et al., 2016	Standard	Mixed	Uniform experience

- Strategy refers to the process by which users plan, prioritise and make decisions in response to system conditions and constraints.
- Social Interaction refers to collaborative or competitive exchanges between users, often facilitated by the gamified environment.
- Feedback loops refer to cyclical processes in which user actions influence future system states, either reinforcing or balancing outcomes over time.

And finally, regarding the aesthetics dimension, defined as the affective and experiential responses generated in the user by the gaming system, the main elements are:

- Immersion refers to the sensory pleasure derived from interacting with multi-sensorial elements.
- Fantasy/Narrative refers to the imaginative context or storytelling that allows users to engage in experiences outside of their everyday reality. Thanks to this narrative dimension, users perceive progression of story elements within the gamified experience.
- Achievements/sense of progression refer to the emotional satisfaction derived from mastering tasks or overcoming obstacles. This element is a direct effect of the challenge element inherent in gamified experiences.
- Fellowship refers to the sense of connection and social belonging achieved through shared play or cooperative engagement.

Table 6 shows how the articles in scope cover the main elements of the MDA.

Across the 23 studies, gamified manufacturing applications track performance through points or scores and provide immediate feedback to the user. This is consistent with best practices that emphasise points, levels and leaderboards as core game mechanics in non-gaming contexts [48, 49]. Time constraints appear in some contexts but is not universally applied. Levels/progression and rewards are also often integrated. In contrast, fantasy themes or narrative storylines are largely absent given that most systems keep the context realistic. The use of social interaction elements is mixed: several studies incorporate competition via leaderboards or team-based goals, and these have been reported to increase engagement and motivation in group settings. However, cooperative "community" elements are rare since gamification is more often used to promote friendly competition or self-competition rather than collaboration. Overall, the most commonly used MDA elements in manufacturing gamification are the "mechanics" of points, feedback and progression, and the "dynamics" of challenge and self-competition that lead to sense of achievement and progression, which have been shown to have positive effects on motivation and

Table 6 Articles in scope analysed through the MDA framework

Authors	Mechanics				Dynamics				Aesthetics			
	Points/Scoring	Levels/Progression/Rewards	Feedback Systems	Time Constraints/ Resource Scarcity	Challenge	Strategy	Social Interaction	Feedback Loops	Immersion	Fantasy/Narrative	Achievement/ sense of progression	Fellowship
Capponi et al., 2025	X	X	X	X	X			X	X	X	X	
Dolly et al., 2024		X	X		X						X	
Agati et al., 2024	X	X	X	X	X				X	X	X	
Capponi et al., 2024	X	X	X	X	X						X	
Ulmer et al., 2023		X	X		X			X			X	
Ohlig et al., 2023	X	X	X		X						X	
Venås et al., 2024	X	X	X	X	X						X	
Zhu et al., 2023	X	X	X		X	X	X			X	X	
Spahrbier et al., 2022	X		X		X					X	X	
Ulmer et al., 2022a	X	X	X		X			X	X	X	X	
Santos et al., 2022	X	X	X		X			X	X		X	
Ulmer et al., 2022b	X	X	X		X			X		X	X	

Table 6 (continued)

Authors	Mechanics				Dynamics				Aesthetics			
	Points/Scoring	Levels/Progression/Rewards	Feedback Systems	Time Constraints/ Resource Scarcity	Challenge	Strategy	Social Interaction	Feedback Loops	Immersion	Fantasy/Narrative	Achievement/ sense of progression	Fellowship
Dewald et al., 2021	X	X	X		X		X	X			X	
Seo et al. 2021	X	X	X	X	X		X		X	X	X	
Ulmer et al., 2020a		X	X		X				X		X	
Ulmer et al., 2020b	X	X	X		X			X			X	
Ohlig et al., 2021	X		X		X						X	
Stadnicka & Deif, 2019	X		X	X	X	X	X	X		X	X	X
Liu et al., 2018	X	X	X		X						X	
Matsas & Vosniakos, 2017			X		X				X		X	
Korn et al., 2017	X	X	X		X		X				X	
Lee et al., 2016	X	X	X		X		X				X	
Roh et al., 2016	X	X	X		X		X				X	

performance. Under-represented are the "aesthetics" of fantasy and community given that few manufacturing studies make use of storytelling or cooperative multiplayer game designs.

4.3 Implementation aspects

Implementation aspects refer to the practical and technological aspects of integrating gamification into the manufacturing environment. It includes the following analytical dimensions:

- Technology implemented: This identifies the technological tools and infrastructures used to support the gamified system. These may include video and audio-based devices, augmented (AR) and virtual reality (VR) systems, digital twin applications.
- Integration into workflow: This dimension evaluates the extent to which the gamified system is integrated into the everyday operational processes of the manufacturing environment. It distinguishes between:

1. Pilot/experimental setup: the gamified system is tested in a laboratory or exploratory context, rather than in the actual production environment. It is usually evaluated through prototypes, rather than being embedded directly into operational workflows.
2. Partial integration: The gamified intervention is implemented in a real working context involving real employees and real tasks. However, it remains in a test phase and is not yet fully embedded in routine operations.
3. Training context: Gamification is applied to training activities rather than production tasks. The system aims to support the acquisition of skills, the transfer of knowledge, and onboarding, without altering day-to-day operational workflows.

- Senses involved: gamification systems, regardless of their domain, always rely on sensory channels to provide feedback, convey information and generate engagement. To better understand how gamification interacts with human perception in industrial settings, it is useful to consider the five classic senses: sight, hearing, touch, smell and taste.
- Usability evaluates whether the system's design considers ease of use, learnability and user acceptance. This includes explicit usability testing, user feedback on interface design and general considerations on adoption barriers. Table 7 will show some comments on the usability of the proposed solution.

Table 7 presents the selected articles analysed through the lens of implementation aspects analytical dimensions.

When it comes to the implementation of gamification in manufacturing settings, several common patterns emerge. Firstly, integration into real workflows is often limited. Many studies have been conducted as pilot/experimental setup or for training activities rather than deployments on the factory floor in everyday activities. Only a few cases approached integration into routine activities. This suggests that, although the feasibility of gamification has been demonstrated, its full integration into routine manufacturing operations remains rare. In terms of technology, most implementations rely on screen-based interfaces and visual feedback. Common platforms include desktop monitors, tablets, and large displays showing real-time performance dashboards, progress bars, scores, and other graphical cues. Visual stimuli (stimulating the sense of sight) are by far the dominant channel in all studies. Some systems add simple audio feedback (e.g. alerts or sound effects) to complement the visuals, but audio plays a secondary role. A few studies explore more advanced or immersive technologies. For example, virtual reality (VR) has been used for training simulations providing multi-sensory engagement through visual, auditory and haptic feedback via controllers [44, 45, 58]. These immersive setups demonstrate the potential for highly engaging training tools, though they are confined to offline training scenarios rather than online production support. Finally, digital twin technology was used in one study [42] in which the gamification interface was linked to a real-time simulation of the shop floor.

In terms of usability, studies generally report positive reception of gamified systems by users. Many authors have noted improved engagement and identified no serious usability issues [43, 56]. These results suggest that well-designed gamified interfaces can enhance the user's experience of work systems without causing confusion. However, the importance of simplicity is often implied, as factory workers may not tolerate interfaces that are overly complex or game-like and which distract from work.

4.4 Outcome assessment

The Outcome assessment category focuses on how gamification interventions are assessed and the tangible results reported. This macro-category evaluates the methodological robustness of the studies and the extent to which they measure meaningful performance or learning outcomes. It includes the following analytical dimensions:

- Objective of gamification: across the various studies reviewed, gamification in manufacturing is consistently used as a strategy to increase work motivation and user engagement. Whether through points, missions, storytelling or immersive feedback, the main goals are:

Table 7 Articles in scope analysed through implementation aspects analytical dimensions

Authors	Integration into workflow	Technology implemented	Sense involved	Usability
Capponi et al., 2025	Pilot/ experimental setup	Video/audio	Sight/hearing	No major usability issues
Dolly et al., 2024	Pilot/ experimental setup	Video	Sight	Reported high engagement; interface judged intuitive in study
Agati et al., 2024	Partial integration	AR/VR	Sight	Simple interface
Capponi et al., 2024	Pilot/ experimental setup	Video	Sight	Acceptability noted as good; straightforward feedback interface
Ulmer et al., 2023	Pilot/ experimental setup	Video	Sight	Usability not explicitly discussed
Ohlig et al., 2023	Pilot/ experimental setup	Video	Sight	Not reported
Venås et al., 2024	Training context	Video	Sight	Generally positive feedback; no integration issues since off-line training
Zhu et al., 2023	Pilot/ experimental setup	Video-DT	Sight	Interface improved user experience
Spahrbier et al., 2022	Pilot/ experimental setup	Video	Sight	High user satisfaction
Ulmer et al., 2022a	Training context	AR/VR	Sight/hearing/ touch	Generally well-received
Santos et al., 2022	Training context	AR/VR	Sight/hearing/ touch	Good engagement in VR; usability acceptable
Ulmer et al., 2022b	Training context	Video-DT	Sight	No usability problems reported
Dewald et al., 2021	Pilot/ experimental setup	Video	Sight	Simple interface for operators
Seo et al. 2021	Partial integration	Video	Sight	Not reported in detail
Ulmer et al., 2020a	Training context	Video-AR/VR-audio	Sight/hearing/ touch	Usability not explicitly discussed
Ulmer et al., 2020b	Pilot/ experimental setup	Video	Sight	Users found system engaging
Ohlig et al., 2021	Pilot/ experimental setup	Video	Sight	Not reported
Stadnicka & Deif, 2019	Training context	Video	Sight	Easy to use in training sessions
Liu et al., 2018	Partial integration	Video-Smartphone	Sight	Good usability reported, high acceptance and satisfaction
Matsas & Vosniakos, 2017	Training context	AR/VR	Sight/hearing/ touch	Some VR usability challenges
Korn et al., 2017	Partial integration	Video	Sight	Good usability reported
Lee et al., 2016	Partial integration	Video	Sight/hearing	Generally well-tolerated by workers
Roh et al., 2016	Partial integration	Audio-Video	Sight/hearing	Reported as user-friendly

•

1. to make work more engaging by increasing attention, emotional involvement or the perceived meaningfulness of the task [9, 16].
2. to increase efficiency, reduce errors and optimise task execution.
3. to enhance training phase of the operators, both for the induction and for the upskilling of workers. This approach is particularly suited to complex procedures, safety-critical operations or environments where traditional training may be less effective or engaging.
4. to strengthen compliance with safety protocols and promote a proactive safety culture.

• Empirical methodology: this dimension captures the type of empirical strategy employed to evaluate gamification interventions in manufacturing. The classification distinguishes between two main categories, which are based on the degree of experimental control and the structure of the study:

1. Controlled experiments that are designed to isolate the effects of gamification through experimental protocols that may take place in laboratory settings, simulated production tasks or real-world environments.
2. Exploratory study that includes pilot implementations, observational and qualitative case studies. They often aim to explore feasibility, gather initial feedback or understand user interaction in early-stage or realistic deployment scenarios.

• Duration effect distinguishes between studies that evaluate only immediate outcomes (e.g. motivation during a task) and those that measure or reflect on short and long-term impact (e.g. sustained engagement, knowledge retention and ongoing productivity). This dimension is classified as follows:

1. Isolated exposure: The gamified system is tested in a one-off session without repetition. The evaluation focuses on immediate outcomes and does not consider duration or sustained use.
2. Short-term exposure: Gamification is applied and assessed over a short time span ranging from a few repetitions within a session to a full work shift. The design allows for limited exposure, but not across multiple days.
3. Long-term exposure: The system is used and evaluated over an extended period, typically several days or weeks, allowing for the observation of sustained effects, behavioural change or long-term engagement.

Table 8 presents the selected articles analysed through the lens of outcome assessment analytical dimensions.

Most performance-oriented studies looked at metrics such as productivity (cycle time and throughput), quality (error rates and accuracy) and process efficiency. These studies often report positive performance impacts. For example, several studies have shown that adding game mechanics can lead to faster task completion and higher quality output [33, 34, 56] which supports the idea that engagement can lead to increased efficiency. Training-oriented studies uniformly found that gamification improves learning outcomes indicating gamification's efficacy in educational contexts. The safety-focused study [58] showed improved hazard recognition and appropriate responses in a virtual environment, suggesting the potential to reduce accidents, although the real-world safety impact would require longer-term validation. While immediate outcomes were typically positive, it's important to note that the magnitude of impact varied and was not always reflected in core performance metrics. A revealing example is that of Spahrbier et al. [43], who found no significant improvement in task performance itself despite the presence of a sophisticated gamified interface for an automated process. However, they find that operators enjoyed the task more and felt more competent and autonomous. This indicates that gamification's value may sometimes lie in improving the user experience and intrinsic motivation rather than directly boosting productivity in the short term. In the long term, such improvements in motivation and satisfaction could lead to indirect benefits, such as better retention or more proactive behaviour at work, although these were beyond the scope of the brief evaluations. However, all the reviewed studies employed empirical evaluations, predominantly focusing on the short-term effects. In almost all cases, the impact of gamification was measured during or immediately after the brief usage, while long-term effects, such as sustained engagement or performance over days, or even months, were not directly assessed, which is a notable gap acknowledged in the literature.

Finally, in terms of empirical methodology, all the studies employed a controlled experiment or an observational study. Many adopted a controlled experimental design, comparing performance with gamification with a baseline (or a control group without gamification). Given the novelty of the topic addressed, other studies were more qualitative

Table 8 Articles in scope analysed through outcome assessment analytical dimensions

Authors	Objective of gamification	Empirical methodology	Duration effect
Capponi et al., 2025	Improve performance	Controlled experiment	Short-term exposure
Dolly et al., 2024	Improve performance	Controlled experiment	Short-term exposure
Agati et al., 2024	Improve performance	Exploratory study	Short-term exposure
Capponi et al., 2024	Improve performance	Exploratory study	Short-term exposure
Ulmer et al., 2023	Improve performance	Exploratory study	Isolated exposure
Ohlig et al., 2023	Improve performance	Controlled experiment	Isolated exposure
Venås et al., 2024	Enhancing training and skill development	Controlled experiment	Short-term exposure
Zhu et al., 2023	Improve performance	Exploratory study	Isolated exposure
Spahrbier et al., 2022	Improve performance	Exploratory study	Isolated exposure
Ulmer et al., 2022a	Enhancing training and skill development	Exploratory study	Short-term exposure
Santos et al., 2022	Enhancing training and skill development	Exploratory study	Isolated exposure
Ulmer et al., 2022b	Enhancing training and skill development	Exploratory study	Isolated exposure
Dewald et al., 2021	Improve performance	Exploratory study	Isolated exposure
Seo et al. 2021	Improve performance	Controlled experiment	Short-term exposure
Ulmer et al., 2020a	Enhancing training and skill development	Exploratory study	Isolated exposure
Ulmer et al., 2020b	Enhancing training and skill development	Controlled experiment	Isolated exposure
Ohlig et al., 2021	Improve performance	Controlled experiment	Isolated exposure
Stadnicka & Deif, 2019	Enhancing training and skill development	Controlled experiment	Isolated exposure
Liu et al., 2018	Improve performance	Controlled experiment	Short-term exposure
Matsas & Vosniakos, 2017	Promoting workplace safety	Exploratory study	Isolated exposure
Korn et al., 2017	Improve performance	Exploratory study	Isolated exposure
Lee et al., 2016	Improve performance	Exploratory study	Isolated exposure
Roh et al., 2016	improve performance	Controlled experiment	Isolated exposure

in nature, reporting user feedback, observations and feasibility assessments.

4.5 Societal impact

Although societal impact is rarely the primary focus of the reviewed studies, some general conclusions can be drawn from the literature, which are common for all the articles in scope. Most gamified systems are introduced to enhance motivation, engagement, training effectiveness or operational performance. However, using gamification as a behavioural design tool raises questions of autonomy, transparency and fairness, especially when feedback mechanisms, performance rankings or reward systems are involved. Few studies explicitly acknowledged these issues, and even fewer provided mitigation strategies or ethical guidelines. Overall, the ethical maturity of gamification in manufacturing remains low. While no problematic implementations were identified, ethical concerns are often underexplored and treated as secondary. Previous studies have shown that gamification can lead to risks such as excessive competitive pressure, stress and social comparison, especially when performance metrics and rankings are emphasised inadequately [72, 73]. Furthermore, over-reliance on quantified indicators can lead to metric-driven behaviours and to goal displacement where productivity scores are prioritised over quality, safety or learning outcomes [74]. In industrial environments, these risks are further amplified by the close integration of gamified systems with digital monitoring and data collection infrastructures, raising concerns relating to surveillance, autonomy, and trust. Finally, transparency regarding how performance data is collected, interpreted and used for managerial decision-making is critical to the acceptance of gamified systems. Addressing these issues is vital to ensure that gamification supports human-centred production rather than reinforcing control-oriented practices [10, 72–74]. As gamification moves from experimental trials to more integrated and operational applications, it will be essential to ensure responsible and sustainable adoption by considering ethical design principles, such as respect for user autonomy, transparency of incentives, clear rules against manipulation and primarily attention to workers' well-being.

5 Discussion and conclusions

This paper provides a structured and original contribution to the study of gamification in manufacturing by introducing and applying a dedicated analytical framework. Drawing from a broad selection of empirical studies, the framework enables a detailed examination of how gamified systems are designed, implemented, and evaluated in industrial contexts. Building on this analysis, the paper also offers a reinterpretation of the Mechanics-Dynamics-Aesthetics (MDA) model to align it with the specific requirements and challenges of manufacturing environments. Each subdimension of the MDA framework is recontextualized to highlight actionable design principles and strategic opportunities. Table 9 synthesizes these insights, proposing concrete ways

Table 9 MDA framework and related proposed application in manufacturing

MDA Dimension	Subdimension	Proposed Application in Manufacturing
Mechanics	Points/Scoring Systems	Quantifying productivity, quality, or collaboration effectiveness
	Levels/Progression/Awards	Mapping skill evolution, certifying training, unlocking advanced tasks
	Feedback Systems	Providing real-time feedback through AR, dashboards, or wearables
	Time Constraints/Resource Scarcity	Introducing timed tasks to boost focus and efficiency
Dynamics	Challenge	Structuring difficulty through tiered goals, unlocking upper levels
	Strategy	Encouraging action planning and decision-making
	Social Interaction	Facilitating team challenges, cooperative objectives, or peer competition
	Feedback Loops	Using adaptive systems to reward sustained improvement or correct errors
Aesthetics	Immersion	Enhancing engagement with multimodal feedback (visual, auditory, haptic)
	Fantasy/Narrative	Embedding tasks within contextual missions or role-based career paths
	Achievements/Sense of progression	Providing gratification for mastering difficult tasks, for achieving goals and for making progress
	Fellowship	Reinforcing team belonging through shared missions or collective goals

in which MDA subdimensions can inform the development of effective gamified interventions in manufacturing, while also pointing to promising directions for future research and practice.

This study employs theoretical models such as MDA and motivational frameworks primarily as interpretative lenses. They support the explanation of recurring design patterns observed in the literature and provide a structured basis to analyse potential relationships between game elements, user engagement and task characteristics in manufacturing contexts. For example, Mechanics sub-dimensions can be used to define structured but flexible workflows in training scenarios, or to guide operators through modular learning paths where available actions are progressively unlocked. Scoring systems can support real-time performance tracking, especially for repetitive or precision-critical tasks, while progression mechanics can be used to visualise individual growth over time, offering meaningful recognition through certifications, ranks or access to advanced tasks. Feedback systems, already common in dashboards, could be extended through smart displays or AR overlays to ensure operators receive continuous, actionable input during live operations. Time constraints, if thoughtfully designed, could add engagement and urgency to tasks.

In the Dynamics category, challenge and feedback loops remain central, but the analysis reveals also potential in strategy and social interaction. Scenario-based planning tasks or gamified simulations could help workers develop problem-solving skills, while team challenges or cooperative goals could reinforce coordination and shared responsibility.

The aesthetic dimension, although less explored in practice, offers powerful insights. Immersion can be addressed through multimodal feedback systems (visual, auditory, haptic), enhancing presence and attentional focus. Narrative and fantasy, when adapted to the context, can transform training activities into experiences with emotional relevance and meaning.

In general, the analysis suggests that simple, mechanics-oriented solutions may be particularly effective for structured, repetitive tasks, and for operators with limited autonomy. In such settings, clear goals and immediate feedback align well with performance-driven work. Conversely, approaches involving richer dynamics or aesthetic components may be more suitable for tasks that require learning, adaptation or collaboration, or for experienced operators. However, such conditions remain under-explored in the current literature. The predominance of simple, mechanics-oriented solutions observed in the analysed studies also explains why the boundary between gamification and conventional production interfaces is blurred. When gamification is confined to the mechanics layer, such as points, scores or performance indicators, without activating corresponding dynamics or aesthetics, systems risk becoming indistinguishable from standard monitoring or control tools. From this perspective, the limited experiential differentiation identified through the MDA lens is an empirical characteristic of current industrial gamification practices. Such insights suggest several promising directions for future research and design:

- Integrating aesthetic dimensions, such as narrative and fellowship, into training and onboarding applications, where emotional engagement and identity building can drive long-term learning.
- Developing adaptive and personalised gamified systems that respond in real time to operator performance, fatigue or skill level.
- Exploring collaborative game dynamics in team-based tasks to enhance not only performance but also trust and social cohesion in increasingly hybrid work environments.
- Evaluating the longitudinal effects of gamification on motivation, skill retention and job satisfaction to understand its role in sustainable employee engagement.

Beyond its analytical value, the framework developed in this study offers an actionable guidance to industrial practitioners interested in using gamification to engage their workforce.

- Firstly, the framework can help managers identify when and where gamification could be beneficial. By explicitly considering contextual relevance, the framework helps decision-makers to consider situations in which gamification can genuinely be effective.
- Secondly, the framework's emphasis on gamification design encourages managers and engineers to move beyond the simplistic reward systems that currently dominate industrial applications. Integrating MDA principles highlights that effectiveness depends on adding points or visual dashboards and on leveraging deeper motivational factors such as challenge calibration, narrative coherence, and social belonging. This is particularly relevant in manufacturing environments, where worker engagement is often influenced by routine, monotony and limited autonomy.
- Thirdly, the framework offers guidance on technological and organisational integration by emphasizing implementation features. For example, managers can use it to decide whether to introduce a gamified intervention via AR overlays, training simulators, wearable feedback devices or existing dashboards. Distinctions are also made between pilot setups, partial integration, and full workflow embedding, helping organisations to plan the adoption of technology realistically and avoid overestimating their readiness for large-scale deployment.
- Finally, the framework emphasises the importance of structured evaluation. Managers often lack the tools to assess the real impact of gamification beyond anecdotal evidence. By distinguishing between short-term performance effects and longer-term engagement and learning outcomes, the framework highlights the importance to discourage the usage of systems that may be unsustainable or ineffective in the long term.

However, this study presents some limitations to be acknowledged. Firstly, although the proposed framework provides a structured approach to analysing and designing gamified interventions in manufacturing, it has not yet been tested in industrial scenarios. Its practical usage, particularly in complex industrial environments with diverse dynamics, remains to be assessed empirically. Secondly, the analysis is cross-sectional; it does not consider how gamified systems evolve over time or how their long-term effects change with prolonged exposure. Longitudinal studies are needed to better understand the sustainability and adaptation of such interventions in dynamic production contexts, focusing also on sustained effects, how operators adapt over time, and the potential consequences of gamification. This aspect also influences the interpretation of the reported empirical effects. Most of the reviewed studies indeed rely on short-term evaluations, which are often conducted in pilot or laboratory settings and may therefore be influenced by novelty effects. Consequently, improvements in engagement or performance should be interpreted with caution, given that their persistence over time and transferability to real-world manufacturing environments remain unverified. Another aspect to be explored is the game impact, since this paper identifies recurring design patterns and dominant gamification elements in manufacturing contexts without explaining why specific elements are effective and for which categories of tasks and operators. Addressing these aspects would require controlled comparative studies and longitudinal investigations, which are currently lacking in the literature. Finally, the study does not explicitly address organisational factors such as management support, cultural resistance or workforce diversity, all of which are likely to influence the success of gamified implementations.

Despite these limitations, this work makes a substantial and novel contribution to the field. As well as providing a structured review of existing applications, it introduces an original analytical framework that synthesises the dimensions of implementing gamification in manufacturing. This framework also serves as a practical decision-making tool for process designers and industrial engineers, providing a vocabulary and structure to support the design and evaluation of gamified solutions. Ultimately, this study opens the way for future research and development that leverages gamification as a context-sensitive tool to support learning, motivation, and operational performance in industrial settings.

Authors' contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by M. Capponi. The first draft of the manuscript was written by M. Capponi under the supervision of L. Mastrogiacomo and F. Franceschini. All authors read and approved the final manuscript.

Funding Open access funding provided by Politecnico di Torino within the CRUI-CARE Agreement.

Declarations

Ethical approval The authors respect the Ethical Guidelines of the Journal.

Competing interests The authors declare that they have no conflict of interest.

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