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THE CONVERGENCE OF COMPUTER-AIDED DRAUGHTING AND DISCRETE EVENT SIMULATION IN MANUFACTURING: A SYSTEMATIC STATE-OF-THE-ART REVIEW

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ABSTRACT

Computer-Aided Draughting and Design (CAD) and Discrete Event Simulation (DES) grew out of engineering sciences related to manufacturing: CAD specifies the geometry of parts, tools and factory layouts, while DES analyses the behaviour of manufacturing systems over time. However, both fields are now becoming linked by the need for shorter commissioning cycles, product changes, and Industry 4.0 digital twins, with the geometric and logistical information already captured in a CAD model already being used to create a simulation study, but not built from scratch. This article is a systematic review of this convergence. According to PRISMA 2020, records from Scopus, Web of Science and IEEE Xplore were identified, screened and assessed for eligibility resulting in the synthesis of 55 peer-reviewed journal articles and conference papers from the period 2007–2025 (49 articles retrieved from the databases and 6 from backward and forward snowballing). Four thematic clusters of literature are presented to organize the literature: (A) automated/semi-automated generation of DES models from CAD and layout data, (B) CAD driven virtual commissioning and behavioural digital-twin simulation, (C) neutral data-exchange standards to link CAD and simulation tools, and (D) digital-twin taxonomies to situate the broader convergence. The review reveals consistent evidence that automated model generation reduces the time to simulation, and that it is easier to learn DES when it is automated, but that there is a loss of information at the CAD–simulation interface, that terminology can differ, and that there is insufficient industry-scale, longitudinal validation. It also considers the implications of the convergence for manufacturers in the developing industrial economies, where the use of simulation is not widely adopted despite the fact that many of the key inputs to the simulation are readily available. The article ends with a research agenda that draws on evidence to support the following points: (1) CAD–DES data exchange via standardised ontologies, (2) hybrid CAD-first vs. event-log-first model generation, (3) terminological precision, (4) human-centred Industry 5.0-oriented modelling, and (5) low-cost convergence pipelines for resource-constrained manufacturers.

Keywords: Computer-Aided Design; Discrete Event Simulation; Digital Twin; Virtual Commissioning; Automatic Simulation Model Generation; Interoperability; Manufacturing Systems; Systematic Review

1 INTRODUCTION

Computer-Aided Draughting and Design (CAD) and Discrete Event Simulation (DES) are two different stages in the manufacturing systems engineering lifecycle. CAD is a tool used by the designer to specify the exact geometry of a part, a tool, a workstation or a factory floor, and DES is a tool used to study the dynamic performance (arrivals, departures, breakdowns and completions) of the same system referred to above. (Negahban and Smith, 2014). Throughout their history the two fields have been used independently: An existing factory design created in CAD would be recreated as a network of queues and process logic in a different simulation package (Dias et al., 2012).

This duplication is expensive. Even an average production line can take hours of expert analyst time to build and validate a discrete-event model, and often the geometric information captured in the CAD model (dimensions, routings, kinematics and bills of materials, etc.) is thrown out and re-input by hand. For the automotive-supplier example, the benefits of this approach are significant: in the car industry, this integration of AutoCAD layout data with WITNESS simulation—via a shared database, has reduced a layout and internal-logistics study from four to one and a half weeks (Dias et al., 2012). There are three reasons why the need to close this gap has grown stronger in the last 10 years. The digital twin, which is a continuously updated virtual replica of a physical asset that combines geometric and behavioural information, has gone from a curiosity to a strategic objective with the advent of Industry 4.0 (Monostori et al., 2016; Tao and Zhang, 2017).

Second, the increasing diversity of products and market dynamics makes an “off the shelf” simulation model rapidly outdated. Flexibility in reconfiguration is one of the key aspects of agile manufacturing, and for Zimbabwean industry, it has been observed that is limited not so much by the lack of appropriate technologies for facilitating reconfiguration, but due to the poor interconnection and optimisation of such technologies (Muhla et al., 2023).

Third, virtual commissioning relies on a CAD-based model and an event-driven simulation of the model's behaviour and therefore is completely reliant on a model generated from the CAD system (Reinhart and Wunsch, 2007; Striffler and Voigt, 2023). For manufacturers, convergence becomes significant for developing economies. In a survey of manufacturing companies in Zimbabwe, the most common Industry 4.0 enabling technologies were the use of computers, sensors and programmable logic controllers (PLCs) while other enabling technologies such as simulation, mathematical modelling software and additive manufacturing were adopted by few companies (Muhla et al., 2025a). If a dedicated simulation specialist is not affordable, then one of the few viable paths toward decisions made with simulation is to utilize the CAD data that design offices are already generating.

This review is a blend of parametric CAD, computer-aided manufacturing (CAM) and discrete-event and process simulation. Instead of CAD and DES being two distinct issues, the question is asked how the literature integrates them, what this integration brings, and where it breaks down.

Its specific objectives are threefold:

- to synthesise the state of the art in generating and exploiting simulation models from CAD and layout data;
- to classify the literature into a coherent taxonomy that disentangles overlapping terminology, namely automatic simulation model generation, virtual commissioning and digital-twin generation; and
- to identify concrete, evidence-based gaps for future research and practice.

2 BACKGROUND AND THEORETICAL FOUNDATION

2.1 Computer-aided draughting and design

CAD systems model a physical object as a geometric model, which is usually constructed using constructive solid geometry (CSG) or boundary representation (B-rep), stored as a history tree of various features like extrusion or revolution, or as a mesh of faces and edges (González-Lluch et al., 2017). The CAD platform is applied at the facility level to digitally layout machines, conveyors and material handling equipment. The model already contains much of what a discrete event model requires in order to describe a production system in both spatial and logical terms, and may include precise dimensional and positional information, and, more recently, kinematic information.

Today's product development takes CAD model further into engineering analysis. Three concepts of the passive upper-limb exoskeleton for reducing fatigue in overhead work were modelled in SolidWorks software and evaluated by finite element analysis using software package Ansys before selecting the best one; the best design was the carbon-fibre design with the factor of safety of 2.1 (Tandi et al., 2025). Functional decomposition and structured concept selection were used in the design of a low-cost dual-mode smart wheelchair (Munotyaani et al., 2026), and of a vertical-axis wind turbine for vehicle slipstream power harvesting, with aerodynamic load analysis and computational fluid dynamics

(CFD) simulation being done before prototyping (Muyambo et al., 2025). From the studies reported it is evident that the design-stage model is now a repository of both behavioural and geometric information. The question to be answered in this review is: Does that information make it to system-level simulation and how.

2.2 Discrete event simulation

The representation of a DES is defined as the entities (e.g. parts, pallets and operators) flowing between resources (e.g. machines, buffers and transport devices) and the simulation clock advances according to events occur rather than in fixed time steps. The software mentioned in the literature are commonly used in commercial environments, such as Tecnomatix Plant Simulation, FlexSim, Arena, Visual Components and AnyLogic, which is also capable of hybrid modelling (discrete-event and agent-based) (Brailsford et al., 2019).

A review by Negahban and Smith (2014) records how the use of DES for capacity planning, bottleneck analysis and evaluation of layout over the last few decades. Prajapat and Tiwari (2017) demonstrate that among the applications of DES, in an assembly application time and throughput are the most common objective functions, and what-if scenario analysis is the most dominant optimisation approach. The credibility of a DES model depends on the input data. In addition to layout and routing it requires processing times, yield and scrap rates, energy usage and failure and repair distributions for every resource and statistically designed process experiments are a direct source for such parameters. Mapindu et al. (2026b) quantify the effects of CNC milling process parameters on surface roughness, tool wear, shrinkage, warpage, tensile strength and print time; Mapindu et al. (2026) quantify the effects of plastic injection moulding process parameters on the surface roughness, tool wear, shrinkage, warpage, tensile strength and print time; and Mapindu et al. (2026) quantify the effects of fused deposition modelling process parameters on surface roughness, tool wear, shrinkage, warpage, tensile strength and print time.

The new setting for the injection-moulding case was expected to achieve lower average shrinkage, from 1.55% to 0.64%, which directly implies reduced scrap and rework in the simulated station, while in the additive case, the settings optimised for strength and those optimised for minimising print time clash on three of four parameters, necessitating a grey relational compromise (Mapindu et al., 2026c). Another study was done to optimize weld strength with gas flow and current as the main factors (Mapindu et al., 2026d). Similar studies on the machining of teak, saligna and pine (Tayisepi et al., 2023), and on the honing of cylinder relining sleeves in cast iron (Tayisepi et al., 2024) as well as on vacuum bleaching of edible oil (Jansen et al., 2025) in a batch process industry correlate cutting parameters with surface quality and cutting energy. In a system-level DES, the impact of parameters on throughput, work in progress, energy consumption can be evaluated instead of just on part quality when such process-level models are incorporated.

2.3 Virtual commissioning

The virtual machine or production line is based on the 3D CAD model, which is then connected to the PLC programme that will ultimately control the actual machine(s) online, allowing the removal of any defects in the control logic before the machine(s) are physically commissioned and ramp-up time is reduced (Reinhart and Wünsch, 2007). Striffler and Voigt (2023) discuss the history of VC, from the early soft version to today's generation of behavioural digital-twin models, and highlight that how useful a VC exercise is will largely depend on the geometric accuracy they deliver, in the context of collision detection, reach and cycle time.

2.4 The digital twin as the point of convergence

The digital twin concept is generally attributed to Grieves's work on product lifecycle management (Grieves, 2012) and was formalized by Grieves and Vickers (2017) as the integration of the physical asset, the virtual model of the asset and the bidirectional data flow between the physical and virtual. Tao and Zhang (2017) extended the concept to the shop floor by introducing the physical components, virtual CAD and simulation models, shop-floor services and twin data. Kritzinger et al. (2018) made a helpful distinction between a digital model (manual, one-way data flow), a digital shadow (automated, one-way) and a true digital twin (automated and bidirectional). This distinction is made in this review since a lot of the literature refers to what Kritzinger calls a digital model or digital shadow, which is created only once from CAD data and is never updated.

To close the loop from the physical system to the virtual model, a live data path is required, and recent research by the authors in Zimbabwe's industry demonstrates the ingredients. Mashava et al. (2026) presented a multi-agent system that both connected infrared temperature sensors, electromagnetic flow meters and conductivity transducers with a Siemens S7-1200 PLC, and provided real-time self-diagnosis of induction-furnace faults, to an OPC server and a FIPA-compliant JADE agent platform. A random-forest model using 13 years of monthly operating data of a thermal power plant revealed that corrective maintenance accounted for approximately 72% of the maintenance mix, and a preventive maintenance regime could be designed with a mean time between maintenance of approximately 300 h (Senda et al., 2026). Data streams and reliability models of this nature are exactly what enable the conversion of a CAD-based

simulation of a digital model to a digital shadow, and back again to a digital model if the decisions are transferred back to the asset, a digital twin.

2.5 Data exchange as the technical bottleneck

CAD and DES are based upon differing internal data models, and therefore information needs to be translated through proprietary translators or neutral exchange formats. The corresponding literature is dominated by two standards: AutomationML, an XML based format which describes plant topology, plant geometry, kinematics and control logic (Drath et al., 2008) and STEP, in particular Application protocol 242: Managed model based 3D engineering (ISO 2020). The Core Manufacturing Simulation Data (CMSD) specification is also adopted for simulation specific content (Zhao, Aghezzaf and Cottyn, 2024). Research in the corpus shows that attributes are not completely transferred even in standardised formats and therefore manual reworking is required.

3 METHODOLOGY AND SEARCH STRATEGY

This review was conducted to explore how the convergence of CAD and DES occur in manufacturing. To follow the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines (Page et al., 2021), the process was broken down into the following steps: identification, screening, eligibility assessment and inclusion, and which have been adopted in recent reviews of automatic simulation model generation (Cimino et al., 2025).

Three research questions (RQs), derived from the objectives in Section 1, guided the review:

- **RQ1.** How, and with what reported benefits, are CAD and layout data used to generate or drive discrete-event and related simulation models in manufacturing?
- **RQ2.** How can the literature be classified so that overlapping concepts (automatic simulation model generation, virtual commissioning and digital-twin generation) are disentangled?
- **RQ3.** What interoperability limitations and evidence gaps remain, and what future research do they call for?

3.1 Databases and search string

The subject literature relevant to the topic was searched in the Scopus, Web of Science and IEEE Xplore databases together covering most of the peer-reviewed manufacturing engineering and industrial informatics literature. The string to search was the title and abstract and keyword fields, and was in the form of a Boolean string:

3.2 Date range and inclusion and exclusion criteria

The main search window was set for the period from January 2016 to December 2025. Backward snowballing was used to include earlier work from 2007–2015 that was frequently referred to by the included studies, thus giving the synthesised corpus historical context, and extending it to 2007–2025.

The records included were those that discussed the use of CAD, factory layout or 3D geometric data as an input to a DES or agent-based or hybrid simulation model; virtual commissioning, the generation of a digital-twin or automated or semi-automated generation of a simulation model in manufacturing; or data-exchange standards (STEP, AutomationML, CMSD) for interoperability between CAD and simulation. Records were rejected if they related to non-manufacturing simulation or were not available for full text and peer-reviewed literature.

3.3 Screening and eligibility

Figure 1 summarises the selection process. A total of 100 records were found in the database. The 10 duplicates were removed, leaving 90 records to be screened according to title and abstract, with 30 records excluded as being too off-topic. Of the 60, 11 were disqualified because they did not meet the snowballing criterion, not all were peer reviewed, they only discussed one component technology, or they were a later journal version of the same study, leaving 49 remaining. Of these, 11 were disqualified, mostly due to not meeting the snowballing criterion and not being peer reviewed, discussing only one component technology, or having been a later journal version of the same study, leaving 49. A total of 49 studies were retrieved from databases using the search strings and 6 studies were retrieved from the databases through backward and forward snowballing, resulting in a corpus of 55 studies.

3.4 Data extraction and synthesis

A convergence mechanism, a simulation paradigm and software, a data-exchange route, an application sector and the type of validation were noted for each included study. Studies were then classified according to the predominant manner in which CAD and DES were linked, resulting in the taxonomy outlined in Section 4.

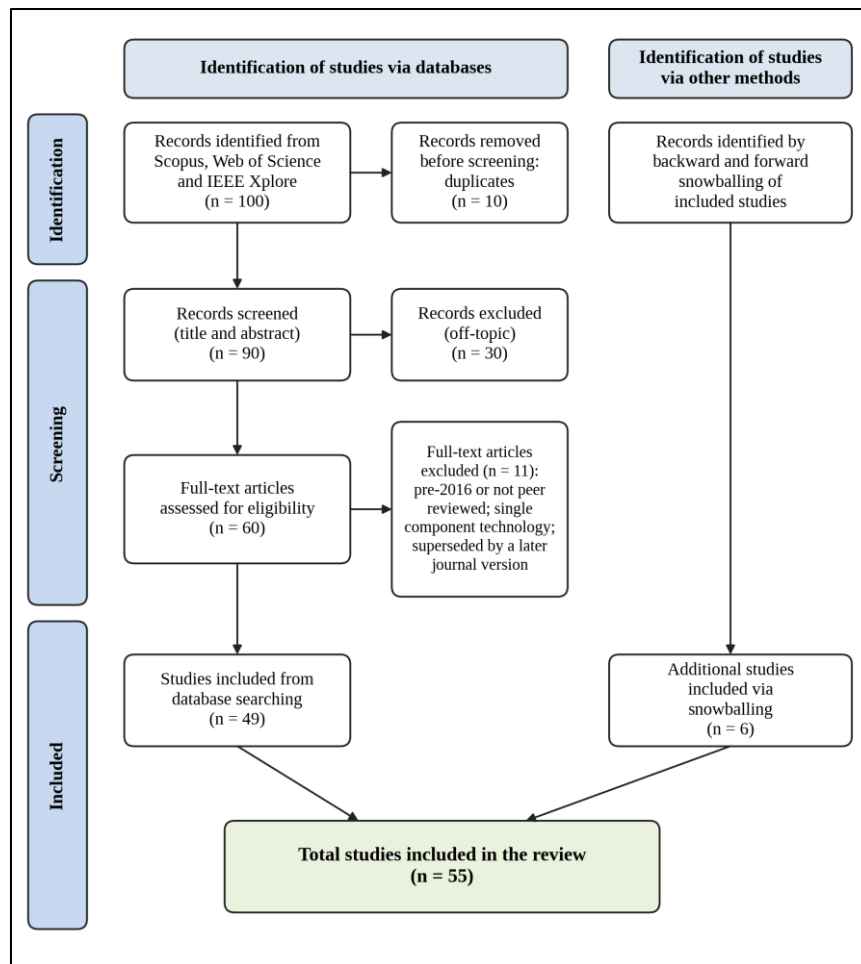


Figure 1: PRISMA flow diagram of the study identification, screening and inclusion process. Source: adapted from the PRISMA 2020 flow diagram template (Page *et al.*, 2021).

4 CLASSIFICATION AND TAXONOMY

The 55 included studies were grouped according to the primary mechanism by which CAD and DES were connected. This produced four clusters: automated DES model generation, virtual commissioning and behavioural digital twins, neutral data-exchange standards, and digital-twin taxonomies (Table 1).

Table 1: Taxonomy of the 55 reviewed studies by convergence mechanism.

Cluster	Main focus	Representative studies	Number of studies	Share (%)
A	Automated DES generation from CAD and layout data	Kanduc and Rodic (2016); Kranz, Nitsch and Mütze-Niewöhner (2023); Lugaresi and Matta (2023); Cimino <i>et al.</i> (2025)	21	38.2
B	Virtual commissioning and behavioural digital twins	Reinhart and Wünsch (2007); Dumitraşcu, Dincă and Predinca (2017); Striffler and Voigt (2023)	14	25.5
C	Neutral data-exchange standards	Dias <i>et al.</i> (2012); González-Lluch <i>et al.</i> (2017); Zhao, Aghezzaf and Cottyn (2024)	9	16.4
D	Digital-twin taxonomies and frameworks	Grieves (2012); Tao and Zhang (2017); Kritzinger <i>et al.</i> (2018)	11	20.0
	Total		55	100.0

4.1 Cluster A: automated DES model generation from CAD and layout data

Twenty-one studies are included in Cluster A, which is the greatest number. Its primary focus is on the ability to speed up the conversion of existing CAD models or factory layout to a usable DES model with minimal rebuilding. According to Cimino et al. (2025), there are four general types of generation methods: data-centric, algorithmic, knowledge-based and interface-facilitating.

Structural and template-based approaches directly map the layout information to the algorithms, objects, and structures of simulations (Reinhardt et al., 2019; Laemmle and Gust, 2019). For instance, Laemmle and Gust (2019) compared various formats of candidate exchange, chose AutomationML and have created an entire robotic-cell model automatically in Visual Components. Operating data, including event logs, is then used to build or refine the model, and CAD information is primarily utilized to verify the physical layout.

Lugaresi and Matta (2021) use data logs to discover the structure of a manufacturing system and generate a tuned DES model in about one minute; they extend this approach to complex material flows by introducing graph-model completion (Lugaresi and Matta, 2023). Kanduc and Rodic (2016) present an algorithmic example in which the layout of the factory itself is included in the optimisation problem, which involves a force generated graph algorithm and simulated annealing; Kranz, Nitsch and Mütze-Niewöhner (2023) trace the recent developments that combine DES with artificial intelligence (AI) techniques for manufacturing planning and control. In all of these approaches, the goal is to minimize repetitive modelling, while maintaining sufficient information to simulate the actual production system.

4.2 Cluster B: virtual commissioning and behavioural digital-twin simulation

The 14 studies in Cluster B are concerned with the integration of three-dimensional and kinematic CAD-based models with control logic to test manufacturing systems prior to their physical commissioning. This becomes very useful if it was expensive to change the equipment or control program after installation. Striffler and Voigt (2023) explain that the depth of the modelling required will depend on the aim of the VC study, and if the aim is to investigate machine behaviour or control logic, then just geometry is not enough. Dumitraşcu, Dincă and Predincea (2017) show how to achieve VC in the Tecnomatix Process Simulate software and how to link the simulation to actual PLC code, while Reinhart and Wünsch (2007) calculate the economic gain in detecting control errors before physical commissioning. Neto and Mendes (2013) demonstrate how a standard CAD program can be used directly to program the robot off-line and Glatt et al. (2018) combine physics-based simulation of material handling with discrete-event material flow simulation. The studies in this cluster thus consider CAD geometry as the beginning of the behavioural simulation process, but not the end of the modelling process.

4.3 Cluster C: neutral data-exchange standards bridging CAD and simulation

Cluster C consists of nine studies and focuses on the technical interactions of CAD, product lifecycle management (PLM) and simulation systems. It is not as large as the other clusters, but it is directly of concern in the implementation, as information needs to move across the boundaries of software before a simulation can use it. STEP AP242 and AutomationML are meant to exchange model-based engineering information and engineering information between heterogeneous manufacturing applications, respectively, (Drath et al., 2008; ISO, 2020). Dias et al. (2012) went a different way, in building a common database as a middle man between AutoCAD and WITNESS, allowing the simulation results to be transferred back into the layout design. Despite the reviewed evidence, it does not indicate that standardised exchange will ensure full exchange. A 7% difference in the number of attributes transferred between routes between FlexSim and Visual Components was seen, with CMSD having a higher number of attributes transmitted across routes than AutomationML (Zhao, Aghezzaf and Cottyn, 2024). This is a rationale for the need of manual checking or further translation steps in many CAD–DES workflows.

4.4 Cluster D: digital-twin taxonomies contextualising the convergence

The 11 studies in Cluster D provide the context behind the broader concepts of the digital twin that were used in the interpretation of the CAD–DES convergence. The aim of these studies is not to focus on any specific CAD-to-simulation mapping approach, but rather to determine the relationship of a digital model to its physical counterpart. Grieves (2012) provided a key foundation on the concept; Kritzing et al. (2018) defined the concept in terms of the direction and level of automation of data exchange, while Tao and Zhang (2017) discussed its application to manufacturing shop floors by connecting physical assets, virtual models and manufacturing data. Further characterisation studies have validated the extent of the use of this term in practice (Jones et al., 2020). It is important for this review because a simulation model that was derived from CAD does not necessarily qualify as a digital twin when there are no updates from the physical system or manual updating. Table 2 below lists the key simulation environments that were found in the literature reviewed. Depending on the platform, the available method of transferring CAD information will be one of the following methods: Native import, neutral standard and custom scripting.

Table 2 summarises the main simulation environments identified in the reviewed literature. The choice of platform determines the available route for transferring CAD information, whether through native import, a neutral standard or custom scripting.

Table 2: Simulation software environments reported in the reviewed corpus.

Software	Paradigm	Typical CAD interoperability route	and	Reported application
Tecnomatix Plant Simulation	DES	Native CAD import; AutomationML	STEP;	Digital-twin generation and virtual commissioning
FlexSim	DES	AutomationML; Manufacturing Simulation Data	Core	Automatic model generation and interoperability studies
Visual Components	DES and 3D emulation	Native CAD import; AutomationML		Factory layout and virtual commissioning
WITNESS	DES	CAD–database intermediary		Layout and process integration
AnyLogic	DES and agent-based	CAD import; custom scripting		Hybrid production-system and virtual-commissioning studies
Arena	DES	Limited native CAD import		Conventional manufacturing-system simulation

5 CRITICAL ANALYSIS AND SYNTHESIS

5.1 Points of agreement in the literature

The 55 studies all have three conclusions. The first relates to effort. Nearly all authors consider the most expensive aspect of undertaking a simulation project to be developing a discrete-event model from scratch, and hope that reusing CAD or layout information will help to reduce as much of this as possible. According to Cimino et al. (2025), the primary challenge to making DES wider is the development time of the models, and in small manufacturing companies who do not have a dedicated simulation specialist, the saving is estimated at about 60% of the project time by Dias et al. (2012) in the case of the integrated CAD–simulation. The logic is the same in the case of virtual commissioning (Reinhart and Wünsch, 2007; Striffler and Voigt, 2023): It's better to invest in a 3D model that can be used for multiple similar lines, than to create a new one for each line.

The second is related to paradigm choice. After CAD geometry was imported, the literature favors the DES approach over continuous and agent-based approaches. Literature indicates that DES is preferred over continuous and agent-based approaches once CAD geometry is imported. Although the use of machine learning and agent-based approaches has increased, DES remains the most popular paradigm in the field of automatic model generation, and according to Brailsford et al. (2019), hybrid simulations using a combination of DES and system dynamics is more prevalent than agent-based modelling. The third is related to interoperability. All the interoperability studies in Cluster C indicate that the transfer of attributes from CAD or PLM systems to simulation tools is incomplete, even with the implementation of AutomationML (Zhao, Aghezzaf and Cottyn, 2024), and in low-level CAD representations, the loss of design semantics is a known issue in PLM contexts (Nzetchou et al., 2022). However, no matter which standard is used there will be some manual correction.

5.2 Disagreements and tensions in the literature

The first tension is around where automation should start. The template-based structural methods consider the CAD and layout geometry as the fundamental aspect of the model (Reinhardt, Weber and Putz, 2019; Laemmle and Gust, 2019). The event log, on the other hand, is the primary entity in process-mining approaches and CAD data is used as a secondary entity used primarily for visualisation and verification (Lugaresi and Matta, 2021). The two roles are based on assumptions that different artefacts are authoritative at a particular lifecycle phase. The as-designed CAD model is always the one that wins out prior to construction but is susceptible to drift, while the as-operated event log is always the one that dominates the system after it is built, but has no role to play in designing the system. No one of reviewed approaches is consistent with the other.

The second strain concerns the terminology. The digital twin already had a broad spectrum of meanings attributed to it in the research on cyber-physical production by Negri, Fumagalli and Macchi (2017), and the corpus confirms the problem: many works talk about the digital twin, but only about a single, manual production of the model in CAD or from scanning data. Digital shadow generation (Kritzinger et al., 2018; Jones et al., 2020), in the absence of an automatic

data stream from the physical system, is the best they can do; and those who make claims on living simulations should take them with a grain of salt.

5.3 Practical implications

The practical implications of integrating CAD with DES depend on the needs of the industry, the production volume and the complexity of the problem:

- **Automotive manufacturing and assembly.** This sector accounts for the largest share of the reviewed literature (around 35%) because of the complexity of assembly systems, the need for ergonomic evaluation and the heavy investment in tooling, which make virtual commissioning and layout design critical (Dias *et al.*, 2012; Dumitraşcu, Dincă and Predinca, 2017).
- **Aerospace and heavy machinery.** Low-volume, high-mix production of large products shifts the focus to space utilisation, crane movement planning and the simulation of complex machining systems (Cimino *et al.*, 2025).
- **Electronics and semiconductor manufacturing.** Automation levels are very high and the emphasis is on automated material-handling systems and automated guided vehicles, where CAD–DES integration is used to optimise traffic flows and avoid collisions in complex topologies; the digital-twin enabling technologies for such tightly coupled systems are reviewed by Qi *et al.* (2021).
- **Fast-moving consumer goods and logistics.** In high-volume, continuous-flow production, line speed and buffer sizing dominate, and detailed 3D visualisation appears to add less value because material moves quickly.
- **Manufacturing in developing industrial economies.** Here the binding constraint is capability rather than technology. Simulation is rarely used (Muhla *et al.*, 2025a), agility is held back by poorly interconnected systems (Muhla *et al.*, 2023), and firms rely on existing PLCs and sensors rather than dedicated twin platforms (Mashava *et al.*, 2026). CAD–DES approaches that reuse existing design and plant data therefore offer the most realistic entry point.

5.4 Upstream data for CAD–DES models in a developing-economy context

The convergence mechanisms reviewed above largely assume a data-rich environment. It is therefore instructive to examine what data are already being generated in a resource-constrained setting. Table 3 maps recent engineering studies from Zimbabwean industry and academia onto the data layers that a CAD–DES model requires.

Table 3: Engineering studies from a developing-economy context mapped to the data layers required by a CAD–DES model.

Data layer	Contribution to a CAD–DES model	Illustrative studies
Product and equipment geometry and behaviour	Validated 3D models, structural loads and aerodynamic performance that define resources and their physical envelopes	Muyambo <i>et al.</i> (2025); Tandi <i>et al.</i> (2025); Munotyaani <i>et al.</i> (2026)
Machining process parameters	Cycle times, surface quality, tool wear and energy per operation for station logic	Tayisepi <i>et al.</i> (2023); Tayisepi <i>et al.</i> (2024); Mapindu <i>et al.</i> (2026b)
Polymer and additive process parameters	Defect (scrap and rework) rates and quality–productivity trade-offs	Mapindu <i>et al.</i> (2026a); Mapindu <i>et al.</i> (2026c)
Batch process-industry parameters	Batch processing times and consumable usage	Jansen <i>et al.</i> (2025)
Reliability and condition data	Failure, repair and maintenance-interval distributions; live data streams for digital shadows	Mashava <i>et al.</i> (2026); Senda <i>et al.</i> (2026)
Human, organisational and skills context	Operator ergonomics and safety constraints, adoption readiness and simulation skills development	Muhla <i>et al.</i> (2023); Muhla <i>et al.</i> (2025a); Muhla <i>et al.</i> (2025b); Ndiyamba <i>et al.</i> (2026)

Two observations follow. First, all of the different layers that a CAD–DES model requires are already present in this body of work, whether it be validated geometry, maintenance intervals, or anything else. Second, each study ends at the component, process or asset level and no one carries the results of any study into a DES at the system level. There is data, but no convergence step is in place to make that data into a plant level decision support. This reflects, on a regional

level, the interoperability and integration shortcomings reported in the international body of work and it offers a practical opportunity which is explored in Section 6.6.

5.5 Limitations of the review

A number of caveats must be noted. This search was limited to three databases, and work was indexed in other databases or in vendor white papers or grey literature may not have been captured. Snowballing partially overcomes this shortcoming, as studies describing CAD–DES integration but not specifically mentioning CAD or DES also might be missed by the search string. For some studies, multiple mechanisms are involved, and judgment is needed to assign each study to a single cluster. Last but not least, the literature is likely to be skewed towards successful single case demonstrations, potentially overstating the benefits of convergence.

6 RESEARCH GAPS AND FUTURE DIRECTIONS

The critical synthesis in Section 5 points to six specific, evidence-based research gaps.

6.1 Absence of a standardised ontology spanning CAD and simulation

After the development of AutomationML and STEP over the past 20 years, none of the studies in the corpus describe a standard that is able to transfer CAD geometry, kinematics, control logic and simulation attributes without measurable loss, with no approach being semantically enriched, so far (Nzetchou et al., 2022). The most important open gap is hence to develop and empirically test the extended ontology which goes beyond CAD to PLM, control engineering and simulation, rather than extending one of these formats only (Zhao, Aghezzaf and Cottyn, 2024).

6.2 Reconciling CAD-first and event-log-first model generation

No study suggests a method of generating an event-log data set that would allow for combining as-designed CAD data and as-operated event-log data in a complementary way, in accordance with the system lifecycle, from design to commissioning to steady-state operation. A formal management of this trust transfer as proposed by CAD – first generation (Laemmle and Gust, 2019) and increasingly delegated to data-driven discovery (Lugaresi and Matta, 2021, 2023) is clearly under-addressed.

6.3 Terminological precision in digital-twin claims

The use of the digital model, digital shadow and digital twin distinction of Kritzinger et al. (2018) should be used consistently in future reviews and primary studies, with any claim regarding a CAD-derived simulation being explicitly stated as to which of these the simulation refers to and what data it supports.

6.4 Human-centred, Industry 5.0-oriented generation methods

Cimino et al. (2025) point out that the human-centric perspective of Industry 5.0, which focuses on human augmentation instead of its replacement, has not yet been reflected in generation research. There are two strands of evidence that explain why this is important. First, human factors have a direct influence on system performance and safety. Ergonomic design was found to be one of the factors contributing to workplace accidents in the manufacturing sector in Zimbabwe (Muhla et al., 2025) and assistive devices like passive exoskeletons are being designed to mitigate operator fatigue (Tandi et al., 2025); however, operator variability and ergonomic constraints are not necessarily represented in CAD-generated DES models. Second, engineers need to know how to interpret and validate results from the simulation (Mourtzis, 2020). Web-based digital twins of miniature production systems (Bellalouna et al., 2026) and VR-enabled virtual commissioning courses (Bellalouna and Reuter, 2026) demonstrate the teaching of CAD models, control logic and simulation together; a proposed framework for learning factories (LFs) in Southern Africa places these in the spotlight as a means to address the Industry 4.0 skills gap in the region (Ndiyamba et al., 2026). Thus, there is a lack of research studying human-in-the-loop approaches for model generation and interpretation (as opposed to fully automated approaches) which are well motivated in practice.

6.5 Longitudinal, industry-scale validation

Most studies, in particular in Clusters A and B, confirm their approach by applying it to a single case in a short period, while few measure the accuracy of the CAD-driven model over a line's operational life (cf. Jones et al., 2020). That leaves open the question of showing the value of a genuine digital twin, rather than a digital shadow, over time. Operational data with a long time horizon (e.g. 13 year boiler record used by Senda et al., 2026) can be used to build the evidence required for longitudinal validation even in resource-limited plants.

6.6 Low-cost convergence pipelines for resource-constrained manufacturers

The mechanisms reviewed are mostly based on the use of licensed commercial software, the dense coverage of sensors, and the availability of an expertise of simulation in-house, which are not likely to be prevalent in developing industrial economies (Muhla et al., 2025a). The pieces are still in place though: PLC or OPC data acquisition on open agent platforms (Mashava et al., 2026), machine-learning reliability models based on plant data and records (Senda et al., 2026) and a growing number of process experiments designed and statistically analysed to produce ready-made station parameters (Tayisepi et al., 2023, 2024; Jansen et al., 2025; Mapindu et al., 2026a, 2026b, 2026c). Research on low cost, open-standard pipelines which bring these data sources together to form system-level DES models is needed, as are assessments of their uptake by SMEs.

7 CONCLUSIONS

The objectives of this review were to review the convergence of CAD and DES in the literature of manufacturing engineering and to assess it using the PRISMA 2020 protocol. The results of the literature search (55 studies between 2007 and 2025) were clustered into four groups: automated generation of DES models, virtual commissioning and behavioural digital twins, neutral data-exchange standards, and digital-twin taxonomies.

In response to RQ1, the most frequently reported advantage of the generation approaches is that a valid simulation model can be built with fewer efforts and knowledge, as reported saving of project time from 60% in integrated CAD, simulation approaches. With respect to RQ2, the four-cluster taxonomy, when integrated with digital model, shadow and twin distinction, segregates the concepts that are often confused. To answer RQ3, the principal challenges are neither in the CAD nor the automation domain, but in the intersection of both: neutral standards like STEP and AutomationML do not support the lossless, bidirectional model transformation yet, and there is no consensus on which data, as-designed CAD data or as-operated events in log, should be trusted at what stage of the lifecycle. The identified opportunities for further work included the existence of a standardised CAD–simulation ontology, the existence of hybrid CAD-first and event-log-first generation, the problem of terminological precision, the problem of human-centred Industry 5.0 methods, longitudinal validation and the problem of low-cost convergence pipelines for resource-constrained manufacturers.

For practitioners, especially those who are not directly involved in simulation, the review recommends that ease of modelling is achieved not through any single tool but through the ability of the systems to communicate with each other through the use of neutral data-exchange formats and that the more tools that are available, and can communicate with each other, the more easily modelling can be achieved. The research findings suggest that for industrial manufacturers in developing economies, much of the information required for CAD-based simulation is already available in the design office, process optimisation studies, or plant maintenance records, and the challenge is to simply link it up.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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There is no conflict of interest.

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