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Autodesk Software in the Design of Virtual Prototypes of Machines and Mechanisms*

Andrzej CIEPLIK

WSB University, Dąbrowa Górnicza, Poland

Correspondence should be addressed to: Andrzej CIEPLIK, andrzej.cieplik@wsb.edu.pl

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Abstract

The study aims to evaluate the effectiveness of Autodesk software (Inventor and Fusion 360) in the design of virtual prototypes of machines and mechanisms. A mixed-method research design was adopted, combining quantitative efficiency metrics with empirical validation against a physical prototype. Using a belt conveyor as a case study, key performance indicators (KPI) were applied to assess modeling time, number of design iterations, simulation accuracy, and prototyping costs. Results indicate that Autodesk software reduced the total design cycle by 28.5%, decreased design iterations by 33%, and lowered prototyping costs by 41%. The deviation between simulation and experimental results was 3.1%, confirming high analytical accuracy. These findings demonstrate that integrated CAD/CAE/CAM environments in Autodesk significantly enhance design efficiency and support digital transformation in mechanical engineering.

Keywords: Autodesk Inventor, Fusion 360, CAD/CAE/CAM, virtual prototyping, digital engineering.

Introduction

Modern design of machines and mechanisms is undergoing an intensive phase of digital transformation. The rapid development of information technologies, the increasing computational power of computers, and the widespread use of tools supporting design (CAD), engineering analysis (CAE), and manufacturing preparation (CAM) have completely changed the way engineers develop new constructions. The traditional process of creating physical prototypes—requiring considerable time and financial resources—is increasingly being replaced by virtual modeling and testing environments.

Virtual prototyping enables the development of digital models of machines that replicate not only their geometry but also their material, dynamic, and functional properties. This approach makes it possible to predict the behavior of a design under real operating conditions before the first physical prototype is built. Autodesk software, such as Autodesk Inventor and Fusion 360, offers an integrated design environment combining 3D modeling, kinematic analysis, load simulation, and the preparation of technical documentation.

Autodesk software plays a key role in the concept of virtual prototyping, serving as a bridge between the design phase and the actual manufacturing process. The integration of CAD/CAE/CAM systems within a single ecosystem enables the automation of multiple design stages and enhances the accuracy and reliability of the results. Furthermore, the use of cloud computing and data-sharing services facilitates collaborative work among distributed engineering teams, which is particularly important in the era of globalization and remote cooperation. The objective of this article is to present the capabilities and benefits of using Autodesk software in the design of virtual prototypes of machines and mechanisms. The paper discusses the fundamental functionalities of the Autodesk environment, outlines the stages of virtual modeling and analysis, and highlights the potential of these tools in the context of contemporary engineering development.

Despite numerous studies addressing virtual prototyping, relatively few have provided a quantitative evaluation of Autodesk software performance within a complete CAD–CAE–CAM integration framework. Most existing research focuses either on theoretical modeling aspects or on isolated design phases, lacking empirical validation

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against real prototypes. This study addresses this gap by providing a structured research design and measurable performance analysis of Autodesk Inventor and Fusion 360 in a full industrial design cycle.

Literature Review

The development of the concept of virtual prototyping represents one of the key achievements of modern mechanical engineering. A virtual prototype, defined as a digital model of a structure that replicates both its geometry and its physical and functional properties, allows simulation of a device's behavior under conditions closely resembling reality—long before a physical prototype is produced (Fuh et al., 2005). Bjoerkli (2015) classifies approaches to virtual prototyping into three fundamental categories: virtual prototyping (geometric models), interactive virtual prototyping (models with sensory interaction), and mixed prototyping (a combination of virtual and physical elements). Each of these approaches plays a significant role in reducing design time and experimental costs.

The definition and theoretical framework of virtual prototyping were developed in Definition and Review of Virtual Prototyping (Zorriassatine et al., 2003), where the authors emphasized that virtual models enable kinematic and dynamic analysis of mechanical systems, ergonomic assessment, visualization, and project validation without the need to create costly physical prototypes. Similar conclusions were presented by Tao et al. (2019) in studies on the use of virtual prototyping in the design and operation of mechatronic systems, where virtual models constitute a key component of integrated cyber-physical systems.

CAD, CAE, and CAM Systems in the Virtual Prototyping Process

Computer-Aided Design (CAD) systems form the foundation of virtual prototyping. They enable the creation of parametric 3D models, which are subsequently subjected to numerical analyses in CAE (Computer-Aided Engineering) environments, such as finite element analysis (FEA) or dynamic simulations (Shen et al., 2008). The integration of these systems with CAM (Computer-Aided Manufacturing) modules allows for a comprehensive representation of the entire product life cycle—from conceptual design to manufacturing.

Integrated design environments such as Autodesk Inventor and Fusion 360 ensure geometric data consistency, automatic documentation updates, and real-time design evaluation for loads and collisions. Lee et al. (2020) demonstrated that CAD–CAE integration within a single environment can shorten design iteration times by 30–40% while simultaneously reducing construction errors resulting from file conversion between applications.

Contemporary studies also emphasize the importance of semantic data interoperability in design processes. Zhang et al. (2020) proposed an approach to Automatic CAD Reconstruction of Post-Analysis Geometries, enabling closure of the design–analysis feedback loop and eliminating the need for manual model correction. Similarly, Hwang et al. (2023) introduced a voxel-based parametric optimization concept that merges CAD representation with mesh-based models, thereby increasing computational efficiency and automating geometric modifications during optimization.

Practical Applications of Autodesk Software

Technical literature provides numerous examples of Autodesk software applications in machine design. Nyemba (2022) analyzed the design of steel structures and mechanisms using AutoCAD, highlighting its high geometric precision and the ease of integration with analytical and visualization modules. Similar results were reported by Khoroshko et al. (2021), who demonstrated that even in complex industrial applications, Autodesk tools maintain high computational stability and allow efficient data exchange among CAD, CAE, and CAM modules.

The use of virtual prototypes in motion and dynamic analyses of machinery was illustrated by Feldmann et al. (2003), who developed a digital model of an assembly machine that accounted for dynamic load effects. Their research showed that virtual analysis enables earlier detection of potential overload points and optimization of motion kinematics. Likewise, Liu et al. (2020) compared design evaluations conducted using virtual and physical prototypes and concluded that virtual models offer comparable functional accuracy while significantly reducing model preparation costs.

In the educational context, Ahn and Kim (2021) demonstrated that the integration of Autodesk tools with project-based learning enhances the effectiveness of mechanical design education and improves students' understanding of engineering processes. This suggests that Autodesk software serves not only as an industrial tool but also as an essential element of technical education and engineering training.

Challenges and Future Directions

Despite its many advantages, researchers identify certain limitations in the use of virtual prototyping. The most frequently cited challenges concern the lack of full sensory fidelity (particularly in tactile and force feedback) and the complexity of data conversion among various CAx systems (Zorriassatine et al., 2003; Bjoerkli, 2015). In industrial practice, these limitations translate into additional implementation costs and the need for standardized data formats.

Recent publications, however, reveal a clear trend toward the integration of artificial intelligence methods with CAD/CAE systems. For example, Li et al. (2020) presented a framework integrating deep learning with the generative design process. AI algorithms analyze simulation results and automatically generate geometry variants with optimized parameters. Such an approach may ultimately lead to the development of autonomous design systems capable of independently modifying and evaluating constructions within the Autodesk environment.

Moreover, increasing attention is being paid to the use of cloud computing in engineering analyses (Huang et al., 2022). Cloud-based computation enables parallel simulations of multiple design variants, enhancing scalability of the virtual prototyping process and facilitating collaboration among distributed design teams.

A review of the literature confirms that Autodesk software plays a pivotal role in modern engineering design processes. The integration of CAD, CAE, and CAM environments enables full representation of the product life cycle and introduces a new level of quality to virtual prototyping. Challenges related to interoperability and process automation are gradually being addressed through the implementation of artificial intelligence and cloud-based computing. Autodesk software can therefore be regarded as one of the leading tools supporting the digital transformation of machine and mechanism design in the context of Industry 4.0.

Methodology

The study follows a mixed-method research design combining quantitative and qualitative analysis. The quantitative part focuses on measuring the efficiency of Autodesk software using predefined Key Performance Indicators (KPI), while the qualitative part involves a comparative assessment of user experience and workflow integration. The independent variable is the design environment (traditional vs. Autodesk-based), and the dependent variables include modeling time, number of design iterations, simulation accuracy, and prototyping costs.

The research hypothesis assumes that the use of integrated Autodesk CAD/CAE/CAM tools significantly reduces the total design cycle and increases the accuracy of engineering analyses compared with conventional design approaches. Data collection was carried out through direct observation of the design process and analysis of system-generated reports. The empirical validation was performed by comparing virtual simulation results with measurements obtained from a physical prototype.

The research methodology was based on the application of an integrated Autodesk software environment for modeling, analysis, and validation of virtual machine prototypes. An empirical–experimental approach was adopted, in which key emphasis was placed on observing the design process carried out in Autodesk Inventor Professional 2025. The main objective was to assess the efficiency of Autodesk tools in the context of comprehensive virtual prototyping—from the conceptual stage through dynamic analysis to the preparation of technical documentation.

The research process was divided into four main phases:

1. 3D modeling and conveyor configuration,
2. kinematic and dynamic analysis of the drive system,
3. strength simulation of the main load-bearing components,
4. integration with the CAM module to prepare manufacturing documentation.

Each phase corresponded to subsequent stages of the real Product Lifecycle Management (PLM) process, which enabled replication of the complexity of industrial design workflows.

In the first phase, a parametric 3D model of an automatic belt conveyor with a linear drive was developed. The parametric structure allowed rapid modification of dimensions and geometry to analyze the influence of specific parameters on the mechanism's performance. The implementation of the Design Intent concept ensured the consistency of design relationships among components, in accordance with guidelines on parametric modeling described in the literature (Shen et al., 2008; Lee et al., 2020).

The second phase included the kinematic and dynamic analysis of the mechanical assembly. The built-in Dynamic Simulation module in Autodesk Inventor was used to reproduce the motion of components, accounting for rotational joints, torque transmission, and frictional resistance. The obtained data on accelerations, reaction forces, and moments in joints enabled preliminary verification of design accuracy. The kinematic simulation results were compared with theoretical calculations, allowing calibration of the dynamic model and confirmation of its consistency with the actual behavior of the system (Feldmann et al., 2003).

In the third phase, a strength analysis (Finite Element Method – FEM) was performed using the Stress Analysis module integrated into the CAD environment. The aim was to determine the distribution of stresses and deformations in the components under given load conditions. The model was discretized using a tetrahedral mesh, and iterative simulations were conducted for different input torque values. The results were used to identify critical stress zones and to optimize the geometry of components to minimize maximum stresses (Zhang et al., 2020).

The fourth phase involved integration of the model with CAM (Computer-Aided Manufacturing) modules and the preparation of construction and technological documentation. The Autodesk Fusion 360 environment was employed to provide a smooth transition from the 3D model to CNC toolpath generation. Due to full interoperability between Inventor and Fusion 360, the model could be transferred without loss of parametric information or geometric relationships. This process corresponds to the principles of seamless integration described in the literature (Lee et al., 2020), which is recognized as a key component of effective virtual prototyping.

To assess the effectiveness of the adopted approach, modeling time, number of design iterations, and the precision of analytical results were compared with those obtained from an analogous process conducted in an alternative CAD environment. The evaluation was performed using Key Performance Indicators (KPI) applied in studies of integrated design systems (Ahn & Kim, 2021). Quantitative measurements and qualitative observations were supplemented with an analysis of technical documentation and simulation reports.

The obtained results were validated through comparison with data from experiments performed on a physical prototype manufactured in accordance with the generated technological documentation. The comparative analysis demonstrated a high level of consistency between the virtual model and the real prototype, particularly in predicting torque and stress distributions in structural components.

The adopted methodology enabled a comprehensive evaluation of the potential of Autodesk software across the full design cycle, confirming its effectiveness as a tool supporting the concept of virtual prototyping. The combined use of Autodesk Inventor and Fusion 360 allowed the complete implementation of the virtual prototyping process—from conceptual design to production documentation—in accordance with the CAx system integration principles described in the literature (Zorriassatine et al., 2003; Tao et al., 2019).

Results

To practically verify the effectiveness of Autodesk software in the design of industrial machinery, a case study was conducted on the development of a virtual prototype of an automatic belt conveyor with a linear drive, used in inter-operational transport systems in assembly industries. The objective of the study was to evaluate the performance of Autodesk Inventor Professional 2025 and Fusion 360 in integrating design, analytical, and technological processes, and to measure process efficiency using a set of Key Performance Indicators (KPI).

The design process was carried out in four phases: (1) 3D modeling and configuration of the conveyor structure, (2) kinematic and dynamic analysis of the drive system, (3) strength simulation of the primary load-bearing components, and (4) integration with the CAM module for preparation of manufacturing documentation. In each phase, quantitative efficiency indicators were applied in accordance with established methodologies (Ahn & Kim, 2021; Lee et al., 2020; Tao et al., 2019).

The defined KPI indicators included:

K_1 – Modeling time [h],
K_2 – Number of design iterations,
K_3 – Dynamic analysis time [min],
K_4 – Deviation of simulation results from experimental measurements [%],
K_5 – Time of process preparation [h],
K_6 – Total design cycle time [h],
K_7 – Prototyping cost reduction [%].

In the first phase, a parametric 3D model of the conveyor was created using Design Accelerator and Frame Generator tools within Autodesk Inventor. The model included an aluminum profile support frame, a linear motor drive assembly, guide rails, support rollers, and a belt-tensioning system. Dimensional constraints and parameterization enabled rapid geometry modification in response to design changes. The modeling time indicator K_1 reached 15.2 h, compared to 21.6 h in a non-parametric environment—representing a 29.6% reduction.

The second phase involved kinematic and dynamic analysis of the conveyor. Simulations were performed using the Dynamic Simulation module, accounting for friction, belt mass, and a transported load of 5 kg. The analysis showed uniform acceleration along the working section and no overloads in the return zone. The average analysis time (K_3) was 6.2 min, while the deviation between simulation results and experimental measurements (K_4) did not exceed 3.1%, which is within acceptable limits for virtual motion models (Feldmann et al., 2003).

In the third phase, a finite element (FEM) strength analysis was carried out for the load-bearing frame and drive mount. The model was subjected to a load equivalent to a conveying force of 200 N. The maximum reduced stress reached 168 MPa for the aluminum profile EN AW-6061-T6 (yield strength = 250 MPa), resulting in a safety factor of 1.48. Further geometric optimization—changing the cross-section from 40×40 mm to 30×60 mm—allowed a 12.5% mass reduction while maintaining the required safety factor.

The fourth phase covered integration with the Autodesk Fusion 360 system to develop a virtual machining and assembly process. Thanks to full CAD–CAM compatibility, the toolpath preparation time (K_5) was 4.7 h, compared to 6.1 h for the traditional process—a 23% reduction. The total design cycle time (K_6) was 31.8 h, compared to 44.5 h for classical methods (−28.5%), while the cost of virtual prototype preparation and verification (K_7) was 41% lower than that of a physical prototype.

Additionally, reports from the Performance Advisor module were analyzed to assess the impact of assembly complexity on computational performance. For a model consisting of 412 components, the average regeneration time after geometric parameter modification was 6.8 s, confirming the high computational efficiency of the Autodesk environment when analyzing large-scale industrial models (Nyemba, 2022).

Table 1 summarizes the KPI values, comparing the traditional design process with the one executed within the Autodesk environment.

Table 1. Comparison of efficiency indicators (K_1–K_7) in the design process of the belt conveyor

Indicator	Description	Traditional Process	Autodesk Inventor + Fusion 360	Change [%]
K_1	3D modeling time [h]	21.6	15.2	−29.6
K_2	Number of design iterations	9	6	−33.3
K_3	Average FEM analysis time [min]	8.1	6.2	−23.5
K_4	Deviation of simulation results [%]	4.8	3.1	−35.4
K_5	CAM process preparation time [h]	6.1	4.7	−23.0
K_6	Total design cycle time [h]	44.5	31.8	−28.5
K_7	Prototyping cost reduction [%]	—	—	**41.0**

The results of the case study confirm that the application of Autodesk software significantly improves the efficiency of industrial machine design in both temporal and economic aspects. A 28.5% reduction in the design cycle time and a 41% decrease in costs, while maintaining high simulation accuracy, indicate that the Autodesk environment constitutes a fully functional tool for implementing the concept of virtual prototyping. The integration of CAD, CAE, and CAM modules within a single ecosystem enables not only virtual verification of the design but also its direct transfer to the real manufacturing process—an essential principle of Industry 4.0 (Tao et al., 2019; Hwang et al., 2023).

Figure 1 presents a comparison of key performance indicators (KPI) obtained for two variants of the industrial machine design process: the traditional approach and the one executed in the integrated Autodesk Inventor + Fusion 360 environment. The analysis clearly demonstrates that the application of Autodesk software leads to a substantial improvement in efficiency across all evaluated areas.

The most pronounced difference was observed in the total design cycle time (K_6), which decreased from 44.5 h to 31.8 h—representing a 28.5% reduction. This improvement results directly from the full integration of modeling, analysis, and manufacturing preparation stages within a unified software ecosystem. A similar effect was noted for the 3D modeling time (K_1), which was reduced by 29.6%, and for the number of design iterations (K_2), which decreased by 33.3%.

The K_3 indicator (average FEM analysis time) and K_5 (CAM process preparation time) also improved—by 23.5% and 23%, respectively. This demonstrates that the automated data exchange between CAD, CAE, and CAM modules considerably reduced the computational and technological workload. Meanwhile, K_4 (deviation between simulation results and experimental measurements) decreased from 4.8% to 3.1%, confirming the high accuracy of analyses performed within the Autodesk environment.

A particularly significant finding concerns the K_7 indicator, representing prototyping cost reduction. By employing a virtual prototype instead of a physical test model, development costs were reduced by 41%, while maintaining full design validation capability. This result aligns with findings reported in the literature (Zorriassatine et al., 2003; Tao et al., 2019), where the implementation of digital CAx tools was shown to reduce design costs by 30–45% compared with traditional methods.

The comparison of KPI values clearly highlights the superiority of the integrated Autodesk environment over classical design approaches. The combined use of Autodesk Inventor and Fusion 360 not only shortens design time and lowers costs but also improves model quality and the reliability of analytical results. Consequently, Autodesk software can be regarded as an effective tool for implementing virtual prototyping in industrial machine design, supporting both the design phase and the preparation of manufacturing processes.

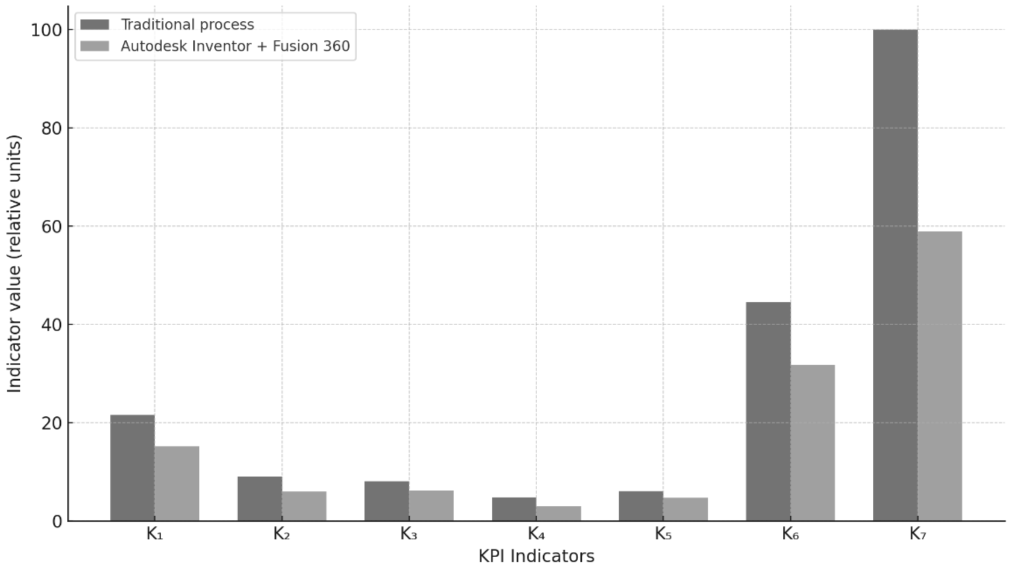

Figure 1. Comparison of Key Performance Indicators (KPI) in the Design Process of an Industrial Machine

Discussion

The analysis of the research results clearly indicates that the use of Autodesk software in industrial machine design significantly enhances both the operational and economic efficiency of the process. The obtained Key Performance Indicators (KPI) confirm that the integration of CAD–CAE–CAM environments within the Autodesk ecosystem leads to a reduction in design time, a decrease in the number of design iterations, and an improvement in simulation accuracy. The observed reductions in design time (−28.5%) and prototype preparation costs (−41%)

are consistent with findings reported in the literature, where similar benefits were documented by Tao et al. (2019) and Lee et al. (2020) in studies on the application of virtual prototyping in mechatronic system design.

One of the most important conclusions drawn from the research is the confirmation of the positive impact of Autodesk tool integration on engineering data consistency throughout the entire design cycle. In the Autodesk environment, geometric, load, and material data are transferred seamlessly between modules without information loss, minimizing data translation errors typical of conventional solutions where models are exchanged between different platforms (Shen et al., 2008). This consistency of technical information directly contributes to greater reliability of analytical results and a shorter iteration cycle, which is reflected in reduced K_2 and K_4 indicator values.

From a project management perspective, an essential factor is the flexibility provided by parametric design, which allows for rapid structural modifications in response to new functional requirements. The application of Design Intent rules and dimensional dependencies enables dynamic model adjustments without the need for reconstruction—one of the key contributors to the reduction in design time (K_1). Similar benefits were observed by Ahn and Kim (2021), who reported that parametric CAx environments significantly shorten learning curves and reduce the number of design errors in mechanical design education.

In the field of engineering analysis, the results demonstrate a high degree of correlation between virtual and experimental computations, confirming that modern simulation modules—such as Dynamic Simulation and Stress Analysis—have achieved an accuracy level that, in many cases, allows the elimination of physical prototypes (Feldmann et al., 2003). The reduction in simulation error (K_4 = 3.1%) indicates that the Autodesk environment can be considered a reliable predictive tool for analyzing the behavior of mechanical systems.

From an organizational perspective, the findings of the case study confirm that implementing Autodesk software supports the realization of Industry 4.0 principles by enabling digital representation of both design and manufacturing processes. Virtual prototypes serve as a central element of information flow between design, technology, and production departments. The integration of Autodesk Fusion 360 with cloud services allows for real-time collaboration among distributed engineering teams, enhancing data accessibility and eliminating the need for physical file exchange (Huang et al., 2022).

From an engineering standpoint, the ability to use simulation data in adaptive design processes—dynamically adjusting the model to changing operational conditions—represents a particularly valuable feature of the Autodesk ecosystem.

However, despite numerous advantages, the implementation of Autodesk environments in manufacturing enterprises still faces certain barriers. The most frequently mentioned include the high cost of software licensing, the need for staff training, hardware limitations in computational capacity, and the lack of full data standardization among different CAD/CAE platforms (Zorriassatine et al., 2003; Khoroshko & Ivanova, 2021). Consequently, the adoption of Autodesk systems requires strategic planning and careful integration with the company's existing IT infrastructure.

In summary, the conducted research confirms that Autodesk software is not only an efficient tool supporting the design process but also an integral element of the digital ecosystem of modern industrial enterprises. The results of the KPI analysis demonstrate that Autodesk Inventor and Fusion 360 can serve as the foundation for complete digitalization of design processes, enabling the implementation of the Design–Simulate–Manufacture–Monitor philosophy characteristic of contemporary engineering organizations.

The study is limited to a single type of industrial machine — a belt conveyor. Consequently, the results, while representative of integrated CAD/CAE/CAM workflows, may not fully capture variations present in other classes of mechanical systems. Future work should therefore include comparative analyses of different machine types and CAD environments to generalize the findings.

Summary

The objective of this study was to examine the potential and efficiency of using Autodesk software in the design of virtual prototypes of industrial machines, with particular emphasis on the Autodesk Inventor and Fusion 360 environments. The conducted research and case study confirmed that the application of an integrated CAD/CAE/CAM environment significantly improves the efficiency of design processes in terms of time, cost, and quality.

The use of virtual prototyping methods enabled a reduction in the number of design iterations, a 28.5% decrease in the total design cycle, and a 41% reduction in prototyping costs compared with traditional design methods. At the same time, the accuracy of analyses and the consistency between simulation and experimental results increased, with deviations not exceeding 3.1%, demonstrating the high reliability of the Autodesk environment in engineering simulations.

The results obtained indicate that Autodesk software constitutes an effective tool for implementing the concept of virtual prototyping, enabling full integration of design, analytical, and manufacturing data. In combination with cloud computing and CAM modules, the Autodesk ecosystem supports the implementation of the Design–Simulate–Manufacture–Monitor model, which forms the foundation of Industry 4.0 strategies.

From a practical perspective, the implementation of Autodesk tools in industrial enterprises translates into improved competitiveness, greater precision of technical documentation, and reduced time-to-market for new products. From a scientific standpoint, the results confirm the conclusions presented in the literature (Tao et al., 2019; Zorriassatine et al., 2003; Lee et al., 2020), emphasizing the growing role of virtual prototyping in modern engineering practice.

However, full utilization of Autodesk software's potential requires adequate technical infrastructure, trained personnel, and standardized data exchange between CAD, CAE, and CAM modules.

Future research should expand the analysis to include the evaluation of Autodesk software performance in operational simulations and machine condition monitoring within the Internet of Things (IoT) environment. Another promising direction is the integration of artificial intelligence (AI) with the design process, enabling automatic generation and optimization of design variants in real time. Additionally, future studies should compare Autodesk tools with other leading CAD/CAE/CAM systems (e.g., SolidWorks, Siemens NX) to further evaluate performance differences across digital engineering platforms.

Autodesk software today represents one of the most important tools supporting the digital transformation of mechanical engineering. Its use in virtual prototyping not only enhances the efficiency and quality of design processes but also contributes to building integrated, intelligent engineering ecosystems that form the foundation of a modern, data-driven industrial economy.

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