Application and Development of EDA Technology in Chip Design: The Evolutionary Path from Traditional Design to Intelligent Optimization

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Abstract: Electronic Design Automation (EDA) serves as a vital tool in the integrated circuit design industry. This paper summarizes the current state of EDA tools and focuses on exploring the convergence between EDA tools and artificial intelligence (AI) technology. It outlines the current development landscape and the challenges encountered. Solutions to overcome these challenges are investigated, and the future direction of EDA-AI tools is predicted.

Keywords: Electronic Design Automation; Artificial Intelligence; Integrated Circuits

1. Introduction

For a long time, as Electronic Design Automation (EDA) tools have developed and matured, they have gradually become a vital component in the integrated circuit design industry. In the 1970s, EDA tools only supported the development of chips with a few thousand transistors. Today, they enable the design of chips with hundreds of millions of transistors and can address ultra-large-scale and increasingly complex integrated circuit design challenges [1]. Regarding the current development of EDA tools, the key challenges they face are primarily: First, compared to the past, today's integrated circuit products have significantly increased in complexity and precision. The performance of EDA tools must keep pace with the advancement of integrated circuits, leading to ever-increasing demands on their capabilities, along with rising development difficulties and costs. Second, the EDA tool development industry suffers from severe technological monopolization by leading companies. The three giants-Synopsys, Cadence, and Mentor Graphics (Siemens EDA)-controlled over 70% of the global EDA market in 2022 [1]. This leaves other IC design firms and EDA developers facing challenges such as technological monopolization and low standardization levels, making it difficult to sustain operations and advance. This paper examines the current state of the EDA industry, outlines the shortcomings of traditional design approaches, and explores how emerging AI technologies are reshaping the EDA landscape. It further analyzes the trend toward integrating AI with EDA tools and their future development.

2. Current Global EDA Industry Landscape

As integrated circuit designs grow increasingly complex and manufacturing difficulties and costs rise rapidly, the global EDA industry landscape is undergoing transformative changes. In recent years, the global EDA industry has maintained stable and positive growth. According to data from the Semiconductor Equipment and Materials International (SEMI) [2], the global EDA industry achieved total sales of approximately $17.8 billion in 2024, representing a year-on-year increase of 6.1%. The average compound annual growth rate (CAGR) over the past five years reached 9.1%, with the market size projected to reach $26.6 billion by 2029, maintaining an 8.5% CAGR. The continuous development of the integrated circuit industry, coupled with rising demand from fields such as artificial intelligence and autonomous driving, will consistently drive the stable growth and expansion of the EDA industry.

The top tier of the EDA industry possesses comprehensive end-to-end products and processes. Due to their intensive R&D investments and well-established ecosystem, they have created significant industry barriers and strong user loyalty. Other companies face significant challenges in achieving technological breakthroughs and capturing market share, which to some extent limits the further development of the EDA industry. This monopolistic trend shows no signs of slowing down. Currently, consolidation among leading EDA companies is accelerating, with firms increasingly moving toward more systematic and comprehensive industrial chains. In November 2023, Siemens completed its acquisition of Insight EDA, addressing gaps in its circuit reliability verification technology roadmap. Cadence acquired system-level solution providers Invecas and BETA CAE in January and June 2024, respectively, addressing structural analysis gaps and solidifying its leadership in multi-domain engineering simulation solutions-aligning with its Intelligent System Design (ISD) strategy. Furthermore, Cadence announced final agreements in January and April 2025 to acquire Secure-IC, a leading embedded security IP platform provider, and to acquire the Artisan foundational IP business from Arm, respectively. These moves clearly define Cadence's strategy to expand its design IP portfolio. The proposed acquisition of Artisan by Synopsys, announced in January 2024, had passed antitrust reviews in major jurisdictions, including the U.S., EU, and UK, by March 2025. If successful, this acquisition would significantly enhance Synopsys' simulation and analysis capabilities.[3]

The convergence of EDA technology with other scientific fields is accelerating, most notably through its integration with artificial intelligence. As early as 2017, the U.S. Defense Advanced Research Projects Agency (DARPA) launched the "Electronic Renaissance Initiative." Its project supporting intelligent electronic device design outlined the goal and direction of combining AI technology with EDA technology to enhance EDA tool efficiency. This initiative leverages AI's machine learning models to codify circuit design expertise, enabling efficient circuit design and testing. This new approach significantly elevates EDA tool performance metrics, injecting fresh momentum into the EDA industry's development trajectory.

3. Transformations AI Technology Brings to EDA Products

The core advantages emerging from the integration of AI and EDA technologies are primarily threefold. First, it represents a highly effective efficiency revolution. For instance, DSO.ai-the industry's first autonomous AI program for chip design-leverages AI to boost staff productivity and innovation. Samsung's chip design team utilized this technology to complete a chip design task that previously took one month in just three days. Such high-performance tools enable developers to avoid redundant work and focus their energy on chip development itself. Simultaneously, cloud-based data sharing enabled by AI allows designers to access and modify data anytime, anywhere, significantly reducing conflicts and misunderstandings caused by data synchronization issues in traditional design. Second, it has achieved a breakthrough in quality within today's integrated circuit design industry. For instance, AI technology is used to check circuit designs for errors, reducing human involvement to lower the workload of manual inspections. It analyzes potential issues and generates reasonable optimization solutions based on requirements. Siemens' software also extensively utilizes AI technology. For instance, Caliber™ Design and Manufacturing Solutions leverage AI to deliver faster and more accurate DRC/LVS/PEX/DFM/REL checks, yield analysis, and reliability optimization, alongside lithography modeling, RET, and OPC, accelerating the NPI process from design to high-volume manufacturing [4]. Third, it unlocks greater innovation potential for the industry. Traditional rule-driven design approaches centered on process and constraints can no longer address challenges arising from multi-chip coordination, system-level optimization, and coupling effects in multi-physics verification. The introduction of AI technology has opened entirely new development pathways for EDA. From circuit design to package layout, and from signal paths to optimized system-level electro-thermal-stress co-simulation, AI is providing the EDA industry with entirely new approaches and solutions to overcome the bottlenecks faced by traditional methods.

4. Current State of AI Integration in EDA Products

Among the global EDA development giants, Synopsys stands out for its AI-driven approach. Its DOS.ai is the industry's first AI-driven chip design tool, effectively reducing design cycles from months to weeks. For instance, in GPU design, it optimizes layout and routing, with solutions deployed by clients like Google and Cambricon. Customers have now deployed DSO.ai across over 700 cumulative chips, with some designs achieving up to 90% SoC block deployment [5]. For industrial-grade validation of Synopsys DSO.ai, this AI-driven layout optimization tool supports searches across hundreds of millions of design spaces. It achieved parameter relocation for RISC-V high-performance computing cores from 5nm to 4nm, completing optimization in just two days while meeting target frequencies and reducing power consumption to 27.9mW. The system achieved a 2x design efficiency boost and significant PPA (Power, Performance, Area) improvements on Microsoft Azure. In Hynix's experimental validation, layout area decreased by 5% and overall chip area shrank by 5%, reaching production readiness [6]. DSO.ai's momentum continues to grow in 2025, driving multiple design orders for flagship CPU and GPU cores. A major AI infrastructure customer has initiated large-scale deployment of VSO.ai across five projects. Furthermore, its AI capabilities are gaining traction in analog design, with a Japanese automotive Tier 1 supplier adopting Synopsys' ASO.ai following extensive evaluation [7]. The widespread adoption of DSO.ai and market trust demonstrate its relatively mature system and comprehensive functionality, serving as a classic example of AI technology enhancing EDA tool performance. DSO.ai continues to evolve through ongoing refinement and upgrades. Synopsys partnered with Microsoft to launch Synopsys.ai Copilot, integrating Azure OpenAI with the EDA toolchain to support natural language generation of RTL code, automated testing, and more. Target clients include industry giants like AMD and Intel. This move signifies DOS.ai's evolution from an optimization tool to a generative AI-driven design collaboration platform. Siemens EDA has also introduced an AI-powered EDA tool focused on printed circuit board (PCB) design, making it more accessible to small and medium-sized businesses (SMBs). Siemens released this tool in June 2025 to lower the barrier to PCB design, enabling resource-constrained SMBs to leverage AI for design optimization. For instance, the tool automates layout and routing tasks through AI algorithms, reducing manual intervention and boosting efficiency. While evidence does not provide specific functional details, contextual inference suggests it may integrate machine learning (ML) models to handle complex design rules, minimize errors, and accelerate time-to-market. This reflects Siemens' emphasis on AI applications within the EDA domain, particularly in the PCB niche market.

5. Issues and Challenges in Integrating AI Technology with EDA Tools

First, to date, core algorithm replacement in AI-EDA tools has not been achieved. Currently, AI primarily functions as a high-level interface (e.g., script generation), while traditional EDA core algorithms (e.g., timing analysis, physical design) still rely on non-AI methods. Large models can serve as advanced interfaces, but they also enhance and improve these algorithms by embedding AI within computational engines or controlling core EDA algorithms in the toolchain. By analyzing logs from previous design runs, they can refine commands and parameters to achieve better PPA (performance-power balance) by analyzing logs from past design runs. This enables dynamic, context-aware optimization strategies beyond static scripting (though this domain is further explored by LLM-free optimization tools like DSO.ai developed by Cadence and Synopsys) [8]. Thus, AI's current role in EDA tool development is primarily augmentation rather than core replacement. For instance, Synopsys ChipArchitect relies on traditional ML techniques rather than emerging LCMs (Large Circuit Models), indicating AI's immaturity in deep tasks like circuit topology understanding and physical property prediction. Second, no entirely new models have been constructed, preventing the full exploitation of AI's advantages. Existing AI-EDA solutions predominantly use general-purpose LLMs (e.g., ChatGPT), lacking native foundational models (LCMs) tailored for circuit design. General-purpose LLMs carry "hallucination risks" in tasks like circuit comprehension and timing inference, and cannot support traceable verification logic. Over 90% of foundational circuit model research began after 2022, indicating this field remains in its early exploratory phase without a stable, reliable LCM ecosystem [9]. Third, data fragmentation and insufficient standardization persist. Fragmented EDA data formats and dispersed process engines hinder unified AI training data . Existing tools like AiEDA attempt to build standardized datasets (iDATA), but their coverage remains limited (only 28nm process) and industry adoption is scarce. Data class and IP core class standards have become monopolistic tools in this industry dominated by three giants, exhibiting high platform dependency. For instance, Cadence employs its proprietary Detailed Standard Parasitic Format and Reduced Standard Parasitic Format, while Synopsys uses its Synopsys Binary Parasitic Format. IP cores contain proprietary intellectual property developed by R&D firms, requiring years of technical expertise and experience to create, resulting in high technical barriers and technology lock-in. Technical lock-in [1]. This relatively low standardization has somewhat constrained the pace of EDA tool development while introducing new challenges for integrating AI technology with EDA tools. Fourth, inherent flaws in AI technology compromise verification reliability. The probabilistic output nature of AI models (especially deep learning models) makes their behavior unpredictable. The same input may yield multiple valid outputs, making it extremely difficult to define "expected behavior" and establish reliable test oracles. When handling probabilistic outputs generated by AI models, minor variations in input data can lead to significant differences in results, complicating the creation of reliable test suites or libraries. Furthermore, a single input can have multiple valid outputs, making it challenging for testers to define expected behavior [10]. Simultaneously, the lack of interpretability poses significant obstacles to debugging and test design. The "black-box" nature of mainstream AI models (e.g., Transformers) results in an uninterpretable decision-making process. This not only increases debugging difficulty but also impedes the effective design of test cases. For instance, tracing error root causes becomes challenging in scenarios like RTL code generation or test stimulus generation. The low interpretability of AI output processes also imposes formal verification requirements on EDA tool validation. Since AI-generated RTL code or assertions may contain syntactically correct but functionally erroneous "hallucinations," mathematical proof through formal verification is mandatory. Otherwise, subtle errors could cause chip tape-out failures and significant losses. This uncertainty poses substantial challenges for further development of AI-EDA tools.

6. Trends and Future Outlook for AI-EDA Products

The powerful computational capabilities provided by AI technology will further reduce labor consumption in integrated circuit design.

The global market recognition and competitiveness of AI-integrated EDA tools demonstrate the vitality and innovative potential of AI-driven directions for the EDA industry. Future R&D will see increased AI application in EDA tool development, while verification challenges posed by AI will gradually be resolved. Emerging solutions include federated learning (enabling cross-enterprise model training while protecting design data privacy to address data scarcity)[11] and synthetic data augmentation (generating problem-code pairs via LLM to enhance model generalization) [12]. Amid the rapid advancement of the integrated circuit industry, AI technology will demonstrate greater developmental potential as computational demands for EDA tools continue to rise.

6.1 Cloud Platforms and Open-Source EDA Tools

As integrated circuit products grow increasingly complex, the traditional on-premises deployment of EDA tools has revealed significant efficiency limitations. The emergence of cloud platforms and the development of open-source EDA ecosystems now provide viable platforms for collaborative development. In the era of intelligence, leveraging artificial intelligence (AI) to free engineers from tedious repetitive tasks is becoming a prevailing trend. This approach can further enhance chip performance and production efficiency. Given AI's powerful applications across numerous engineering domains, we have reason to believe AI can deliver significant value to EDA. However, the precision of AI infrastructure within EDA-such as open-source EDA toolkits and packages-accessible labeled data for EDA tools, AI model configuration, and systems-is crucial for providing valuable AI models to EDA.

6.2 Full-Stack AI-EDA Tool Commercialization

AI-EDA tools have undergone initial market validation with promising outcomes. Following Synopsys.ai's launch as the world's first full-stack AI-driven EDA suite, other vendors are accelerating development in areas like 3D integration and in-memory computing. AI-EDA tools are poised to reach a new peak in commercialization.

7. Conclusion

Against the backdrop of rapid development in today's integrated circuit industry, the application scenarios for EDA tools are expanding, and performance requirements are intensifying. The development of EDA tools is poised for significant transformation and innovative approaches. Among these, the emergence of AI-EDA tools stands out. Currently available AI-EDA products demonstrate substantial potential and promising prospects, yet they also face numerous challenges that are difficult to resolve in the short term. As the technology matures further, AI-EDA tools will demonstrate greater power and potential within the integrated circuit industry.

Future research should focus on addressing key challenges faced by AI-EDA tools, such as core code implementation and AI verification issues. It is also crucial to observe and analyze the trend toward full-stack AI-EDA tools. This full-stack integration has emerged as a new industry direction and serves as a significant driving force for combining EDA tools with artificial intelligence.

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