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Abstract. The paper is a review of the implementation of artificial intelligence (AI) in electronic design automation methods and tools. The implementation of AI in Modelling, Simulation, Synthesis, and integrated circuit (IC) Layout electronic design automation (EDA) Tools is first considered then the AI for printed circuit board (PCB) design tools is studied. The knowledge base and machine learning (supervised and reinforced learning) with neural networks (NN), multi-objective optimization, and hybrid method and the corresponding mathematical methods are discussed. Validation examples are considered. Since AI is a breakthrough innovation factor, the impact of its current and expected implementation in EDA tools by company developers on the market is discussed.

Keywords: AI, ML, EDA tools, EDA companies, Modeling, Simulation, Synthesis, IC Layout design, PCB design.

1 Introduction

The incorporation of Electronic Design Automation (EDA) integration can enhance product development and design processes by harnessing knowledge and reasoning capabilities. This transformation has a profound impact on the utilization and effectiveness of EDA systems. While initially conceived as a basic tool, top-tier EDA software solutions have evolved to encompass sophisticated functionalities, enabling users to execute tasks that were once beyond the realm of traditional methods. Artificial Intelligence (AI) stands as a pivotal force propelling the potential of EDA to new heights. Several leading EDA software solutions have begun integrating Artificial Intelligence.

The infusion of AI into EDA yields several noteworthy outcomes. AI can amass and generate knowledge-based information, seamlessly integrating it into EDA procedures to amplify automation. AI algorithms possess the capacity to autonomously implement necessary design adjustments, obviating the need for human intervention. AI can also expedite the testing and simulation processes, thereby reducing design time. [1]

The papers study the implementation of AI for solving EDA tasks in structural/behavioral/topological design areas with different AI approaches, mathematical methods, and validation examples as presented in Table 1.

Table 1. AI for solving EDA tasks and applications and in the design area with different AI approaches and mathematical methods.

Application designs	Design tasks/ Design area	AI approach	Mathematical methods	EDA tools
Analog circuits RF circuits	Modeling/ Behavioral area Simulation/ Behavioral area Synthesis/ Structural area Optimization/ Behavioral, Structural, and Topology areas IC topology design/ Topology area	Knowledge base/Expert system Machine Learning (supervised/ reinforced learning) •NN •Multi-objective optimization •Hybrid	•Artificial Neural network (ANN) •Bayesian Neural Network (BNN) •k-nearest neighbors (KNN) •Deep learning (DL) •Genetic algorithm (GA) •Decision tree •Random forest •Strength Pareto Evolutionary Algorithm-2 (SPEA2), •Bayesian Optimization •Evolutionary algorithm optimization •Lower Confidence Bound (LCB) functions •Non-Dominated Sorting Genetic Algorithm II (NSGAII) •Multiobjective evolutionary algorithm based on decomposition (MOEA/D) •Bayesian Regression •Support Vector Machines (SVM), •Polynomial Regression, •Sparse regression •Rectified linear unit (ReLU)	Spice simulator
PCB design	PCB Layout design/ Topology area			Continuity, New Celus [5], JITX [4], Circuit Tree [6], Tomy Day and Circuit Mind,

The report in [21] discusses the potential financial impacts of AI using general industry trends and the known benefits of AI. The metrics of operational efficiency, cost savings, revenue growth, customer satisfaction, and market share are explored in a qualitative manner.

2 Implementation of AI in Modelling, Simulation, Synthesis, and IC Layout EDA Tools

AI is implemented in Modelling, Simulation, Synthesis, and IC Layout EDA Tools.

2.1 Behavioral Verilog-A models based on Machine Learning in TechModeler

TechModeler [2] employs neural network-based modeling and is capable of handling a substantial quantity of variables and nonlinear occurrences for temperature impact and autonomous warming depiction, corner representation for device disparities, reliability simulations for both devices and circuits and sound representation. The theorem of generality asserts that a neural network featuring a sole concealed layer has the capability to approximate a continuous function to an aspired accuracy level. By employing a sufficient number of concealed neurons, it is conceivable to identify a neural network whose output is represented with the desired precision for all input scenarios.

2.1 AI in Analog IC Design

Analog integrated circuits (ICs) continue to lack a significant level of automation, which is customary in fully automated digital circuit design. Instead, they rely on the designer's expertise.

The research in [9] primarily concentrates on techniques to reduce the design cycles of analog circuits, specifically in the topological layout design. Various automation methodologies are explored. Advances in high-performance computing hardware have opened doors to machine-learning solutions for designers. Reference [9] conducts an examination of machine learning methods applied in analog circuit sizing and evaluates their efficacy.

Three primary categories of machine learning techniques are investigated:

- Artificial neural networks (ANNs) (both shallow and deep) utilize supervised and reinforcement learning methods [14] to model intricate nonlinear problems, thanks to high-speed computers. The fundamental concept of ANNs involves constructing a model that approximates the actual solution for a problem based on a dataset (training phase). Concurrently, the model should possess the ability to generalize and predict new outcomes for previously unseen data (testing phase) with predefined accuracy. Validation using operational amplifiers is accessible. The automated sizing of all operational amplifier components offers advantages to circuit designers, allowing them to concentrate more on optimizing macro-system performance and architecture. The criteria for assessing supervised learning in analog circuit design, as proposed in [9], include: Dataset generation approach; Feature selection; Complexity of ANNs; Utilized IC fabrication process; Targeted circuit types; and Method for validating results. In IC design, Reinforcement Learning is not widely employed.
- Multi-objective optimization employing various heuristic and stochastic strategies, simulation-based optimizations such as Bayesian, particle swarm, Gaussian process, simulated annealing, and genetic algorithms (although not strictly considered ML techniques).
- Hybrid approaches that combine global optimization and ANNs. The concept behind hybrid methods is to initially employ multivariate polynomial regression to estimate performance trade-offs in optimization and predict circuit performance under new conditions. Subsequently, the outputs are input into an ANN, which learns from these updated examples to predict device sizes corresponding to the new performance.

The objective is to efficiently reuse existing designs to predict circuit performance under novel circumstances.

A portion of the ANN design is tackled by a genetic algorithm (GA), iteratively deciding which performance metrics and design constraints to include as input features during training. Constraints on design parameters become additional inputs to the GA-ANN combination, aiding in reducing under-determination levels.

A learning framework based on evolutionary algorithm optimization, coupled with an embedded ANN, entails deriving a new design from the previous one (a population-based method) at each optimization step. The ANN aids in the sampling process, selecting the best candidate design for the next generation. Predicting whether a design surpasses its parent is executed by a Bayesian ANN that emulates the circuit simulator with enhanced speed. Initially, SPICE simulations are used alongside the GA, and a trained ANN determines the local minimum search for neighboring design regions.

Hybrid techniques harness ANNs for diverse purposes, either replacing time-consuming IC simulators that impede global optimization or expediting sampling or search exploration within the algorithm itself. In some instances, hybrid methods employ a genetic algorithm to design the optimal ANN structure and select features for training.

Monte Carlo simulations [18] are employed to develop and train artificial intelligence (AI) and machine learning (ML) models. They aid in evaluating model performance, estimating uncertainties in predictions, and determining confidence intervals for model outputs. Monte Carlo simulations prove particularly valuable in reinforcement learning, where they facilitate the exploration and optimization of decision-making strategies within complex environments.

2.2 Machine learning techniques in analog/RF integrated circuit design

Machine learning methodologies in analog/RF integrated circuit design are examined in [10]. ML training and simulation generate a model that adapts the specified objectives of RF design. Decision Tree can be employed to automatize the selection of a circuit topology based on the desired specifications; Random Forest is utilized to detect potential rare occurrences during the Monte Carlo simulation of RF design. Support Vector Machines and ANN-based strategies are frequently employed to acquire the functional models of analog circuits.

- SVM is applied for modeling Analog Circuits - GaAs transistors and Analog Circuits-CMOS. ANN is utilized for modeling AMS circuits-CMOS, RF-microwave components, HMT and MESFETs, RF-CPW components, and RF-UC-PBG rectangular waveguide [10].

- ML-driven IC circuit synthesis applications for Analog Circuit Enhancement encompass KNN, ANN +SPEA2/GA, Bayesian Optimization (GP+LCB+NSGA-II BNN+LCB+MOEA/D), for Performance Space Exploration, include Bayesian Regression (GA+SVMs), Polynomial Regression, ANN-based information retrieval +Sparse regression [10],

- Techniques employed for Analog Circuit Synthesis consist of ANN (GRP+MLP), DL+RELU, Polynomial Regression + ANN, RL (L2DC), and Deep RL, for RF Circuit Synthesis - GA+ANN(MLP) [10].

- ML applications for layout automation in Placement incorporate ANN with nxWxH neurons, and ANN with 3 or 4 concealed layers., for Routing - ANN is employed as VAE [10].

Pareto optimal fronts are estimated for the designed circuit in a novel context.

The SPICE tool serves the simulation phase in ML-based analog/RF circuit optimization.

3 Implementation of AI in PCB Design Tools

The electronics industry has witnessed a significant rise in the adoption of artificial intelligence (AI) in the field of PCB design. AI-driven approaches have emerged as powerful tools, revolutionizing traditional design processes and addressing various design challenges. The integration of AI in PCB design offers numerous benefits, although it also raises considerations regarding limitations and potential concerns [3] [12] [13].

The rising integration of AI into PCB design stems from a variety of reasons. First off, the escalating complexity of electronic systems calls for advanced design approaches. AI algorithms are particularly adept at managing large datasets and intricate decision-making processes. They harness the power of machine learning to sift through extensive design data, identify patterns, and make well-informed decisions around component placement, routing, and optimization. This empowers PCB designers to effectively address complicated design issues and secure exceptional outcomes [3] [13].

In the world of PCB design, strategies powered by AI bring several advantages to the table. One of the standout benefits is a significant boost in design productivity. AI algorithms have the capability to take over repetitive and time-intensive tasks, such as figuring out component placement, routing, and analyzing signal integrity. This automation allows designers to free up their time and concentrate on more critical design aspects like system-level optimization and innovation. Thanks to the heightened efficiency and productivity AI tools offer, the design cycle is sped up, paving the way for electronic products to reach the market more swiftly [8].

Moreover, integrating AI into PCB design proves effective in overcoming prevalent design hurdles. For example, smart algorithms have the ability to fine-tune component placement to keep signal interference to a minimum, cut down on electromagnetic coupling, and enhance thermal management. By evaluating different design constraints and performance needs, AI algorithms can pinpoint the best solutions that comply with design specifications, all while taking into account elements like power distribution, signal integrity, and heat dissipation. These features lead to an uplift in design quality, fewer design iterations, and a boost in the overall performance of the electronic system [3] [13].

Furthermore, AI-driven tools facilitate design exploration and optimization. They can generate and evaluate multiple design alternatives, considering different trade-offs between cost, performance, and manufacturability. Designers can explore design spaces more efficiently, allowing for better exploration of innovative ideas and design improvements. AI algorithms can quickly assess the impact of design changes, enabling rapid prototyping and iteration. This iterative design process leads to faster convergence on an optimal design, ultimately enhancing the final product's quality and functionality [13].

In [11], a proficient system employing statistical examination of the defect repository is employed to diminish the duration required for PCB testing. Leveraging insights from the defect data, the defect pattern can govern operations at the production facility.

AI-powered PCB design tools and solutions intensively developed are: Continuity[4], New Celus (Germany)[5], JTX, Circuit Tree [6], Tomy Day, and Circuit Mind and Zuken [3][7].

4 Market Impact of the Integration of AI in EDA Tools

AI is a breakthrough innovation factor [19, 20], and the impact of its current and expected implementation in EDA tools by company developers on the market is considered in this section.

A recent investigation [21] suggests that enterprises employing artificial intelligence (AI) and its affiliated technologies are poised to secure superior profits as opposed to those that abstain from their utilization. The imminent horizon appears to herald a prosperous period for entities that are implementing AI. The amalgamation of AI and exploratory data analysis (EDA) can expedite product innovation.

In the forthcoming years, firms channeling resources into AI are anticipated to reap greater short-term advantages. The outlook for the design, automotive, engineering, and manufacturing sectors is predominantly contingent on AI technologies.

The evolving technology industry is marked by innovation and the increasing significance of technologies, like artificial intelligence generative design, and machine learning. According to GlobalDatas report [17] on Innovation in Artificial Intelligence; AI assisted CAD there have been over 3.6 million patents filed in the technology sector in years. The progression of these innovations is not a path. Rather resembles an S-shaped curve starting with emergence moving towards adoption and eventually reaching maturity.

Within this realm of innovations, AI-assisted computer-aided design (CAD) stands out as a transformative breakthrough. This technology leverages the capabilities of intelligence to automate design processes. Its advantages include design creation, streamlined workflows, and improved user interfaces. This innovation represents a shift from methods to AI-powered processes that save time while enhancing accuracy.

GlobalData identifies over 900 companies involved in the development and application of AI-assisted CAD. These companies encompass stakeholders such as technology vendors established tech firms with a standing presence, in the industry as well as emerging start-ups. The report classifies these companies based on two factors; "Application diversity" and "Geographic reach". The first term refers to the uses associated with each patent classifying companies as diversified innovators. The second term represents the countries where each patent is registered indicating its impact [17].

Leading the way, in patent filings is the State Grid Corporation of China primarily concentrating on developing testing techniques for wind power plant parameters. Other important players in this field include Halliburton, Siemens, Arrow Electronics, and Vektor Medical all making contributions, to this domain.

The advent of Artificial Intelligence (AI) has revolutionized many industries, including Printed Circuit Board (PCB) design. This report investigates the impact of AI on the financial performance of three leading companies in this sector: Zuken (Japan) [15], JITX (USA), and Continuity, now Celus (Germany) [3][4][5][16]. The state-of-the-art of the market impact can be centered around five key areas: operational efficiency, cost savings, revenue growth, customer satisfaction, and market share.

- Operational Efficiency: The integration of AI into the design process could reduce the time required for design tasks, indicating an improvement in operational efficiency.
- Cost Savings: AI implementation in design tasks may reduce related expenses, suggesting a positive impact on financials.
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- Revenue Growth: The successful integration of AI tools could potentially boost the market demand for their services, indicating an increase in revenue.
- Customer Satisfaction: By reducing human error and enhancing design quality, AI can potentially improve customer satisfaction rates.
- Market Share: An increase in market share following AI implementation may suggest that the company's AI solutions are competitive and well-r.

The integration of AI in PCB design appears to offer substantial financial benefits such as increased efficiency, reduced costs, improved customer satisfaction, and potential for market share growth. However, the magnitude of these benefits will depend on the specific AI technologies used and the effectiveness of their integration.

5 Conclusions

The overview of the implementation of AI in EDA methods and tools has permitted us to identify the state-of-the-art in EDA tasks and applications and the design area with different AI approaches and mathematical methods. It was noticed that research in AI for EDA is intensifying and s number of solutions are already available. Challenges are also identified.

Machine learning-supported methods for automated dimensioning have not been investigated for analog circuits where transistors function as toggles. Circuits necessitating lengthy transient assessments are unsuitable for hybrid methodologies employing evolutionary algorithms, which are also time-consuming.

Despite the many benefits, the integration of AI in PCB design also presents certain limitations and potential concerns. One limitation is the need for large amounts of high-quality training data. AI algorithms rely on extensive datasets to learn and make accurate predictions. Obtaining comprehensive and diverse datasets specific to PCB design can be challenging, particularly in specialized domains or niche applications. Acquiring and curating relevant training data remains crucial to ensure the effectiveness and reliability of AI-driven design tools.

Another concern is the interpretability and transparency of AI-generated designs. As AI algorithms often operate as black boxes, it can be challenging to understand the decision-making process and validate the rationale behind design choices. Ensuring transparency and providing designers with insights into the reasoning behind AI-generated design recommendations is vital for trust and effective collaboration between AI and human designers.

Additionally, the expertise and experience of human designers remain invaluable. While AI algorithms can automate certain aspects of the design process, human creativity, domain knowledge, and intuition are still essential for tackling complex design challenges and pushing the boundaries of innovation. The successful integration of AI in PCB design requires a collaborative approach, where AI augments human expertise and provides powerful design tools, while human designers contribute their unique insights and creativity.

The hardest problem in AI is to give the ability to distinguish between the relevant and irrelevant.

AI holds significant potential for companies in the PCB design industry. While the exact financial impacts will vary among companies, the general trend suggests that AI can lead to increased efficiency, cost savings, improved customer satisfaction, and increased market share. As AI technology continues to advance, its potential financial benefits are likely to increase. Further research involving specific financial data would provide more concrete insights into the financial impacts of AI on these companies.

In the forthcoming era, the impacts of AI-linked CAD technologies are poised to intensify even more.[1]

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