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Open Source Integrated Circuit Design Tools in Scientific Research: Yay or Nay?

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Abstract: *The design of integrated circuits (IC) has a significant impact on the development of modern world technologies. The subject of this research is the examination of the potential application of open source tools for integrated circuit design in scientific research. This paper analyzes some open source tools. The research results show that the application of these tools has advantages and disadvantages as well, but most importantly, in the context of science that it is feasible and even recommended. Open source tools for integrated circuit design create positive outcome of the financial feasibility of scientific research activities, collaboration, and the advancement of scientific research. The paper also presents possible future research in this area.*

Keywords: *ic design; open source tools; VLSI; research; academia*

1. INTRODUCTION

In modern society, which is evolving with the development of technology, the possibilities for applying electronics are continually growing. The popularization of electronics as a field is influenced by the development of consumer electronics, process automation, the Internet of Things (IoT), robotics, and more [1]. The academic community, including educational and research segments as well plays a significant role in the advancement and promotion of electronics.

A crucial area of electronics for modern technological transformation is integrated circuit (IC) design. IC design involves the design and development of electronic components integrated into a single chip [2]. This allows for the integration of a large number of functionalities into small and efficient components, which promotes the development of communication systems, medical devices, consumer electronics, the automotive industry, and more. This integration simplifies the production of complex devices, improves device performance, reduces power consumption, increases data transfer speed, enables the development of small and lightweight devices, and more.

The complexity of IC design makes use of appropriate tools necessary in order to meet market demands. To satisfy these demands, there are different categories of tools used in IC design. On one side, there are high-quality tools that offer better functionality but as a drawback bring a higher price, while on the other side, there are open-source solutions that, although free, have certain functional limitations.

The target audience in this field can be divided into two groups: industry and academia. Therefore, it is important to consider them separately. This paper analyzes some open-source tools to examine the possibility of their active use in academia, specifically for scientific research purposes, to meet the needs of the scientific community.

2. LITERATURE REVIEW

It is notable that the world of integrated circuit design is dominated by proprietary tools developed by companies such as Cadence [3], Synopsys [4], and Mentor Graphics [5]. Besides commercially available tools, it is important to note that open-source tools are becoming more popular in this field. These tools are maintained by organizations and volunteers who are committed to making field of integrated circuit design freely and openly available for universities, as well as for individuals and smaller companies that cannot afford licenses for proprietary tools. Typical examples of open-source tools include Magic, Klayout, Qflow, Qrouter, IRSIM, Netgen Static, and Yosys [6-8]. Currently, the use of open-source tools in scientific research is not sufficiently covered, resulting in a lack of awareness among the scientific community about these tools. As a result of that, the open access, adaptability, and other benefits of these tools are not reaching the scientific community.

In the following text, the selected tools will be briefly presented with their intended purpose and basic use methods.

2.1 IRSIM

IRSIM is a tool intended for the simulation of digital circuits using switch-level simulation, which involves modeling transistors as switches whose real characteristics are simulated using extracted capacitance and lumped resistance values [9], [10]. The IRSIM tool supports operation in a graphical environment, as shown in Figure 1, and also supports command-line operation using the Tcl/Tk scripting language, as shown in Figure 2.

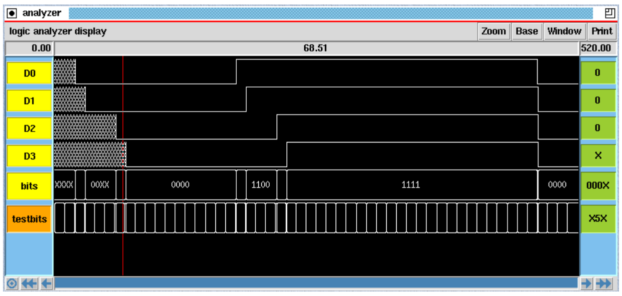

Figure 1. *The "analyzer" graphic display in IRSIM* [9]

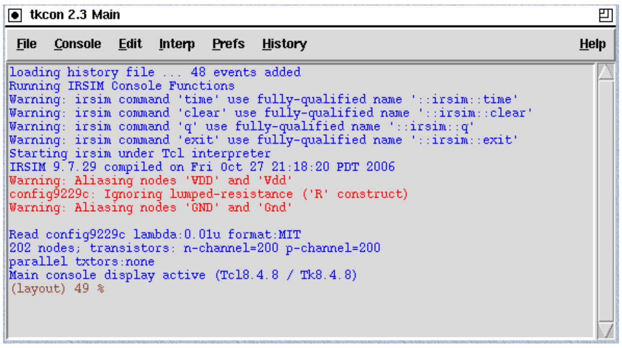

Figure 2. *The IRSIM command console in the Tcl/Tk* [9]

2.2 Magic

Magic is a tool intended for the physical design of circuits in both the analog and digital domains. Although the tool originated in the 1980s, continuous improvements have made it fully compatible with modern standards and integrated circuit manufacturing processes. Magic can be used through a graphical interface (Figure 3) as well as via the Tcl/Tk command console (Figure 4). As addition to that, Magic can be used independently or as part of the Qflow toolchain as well. Qflow will be discussed later.

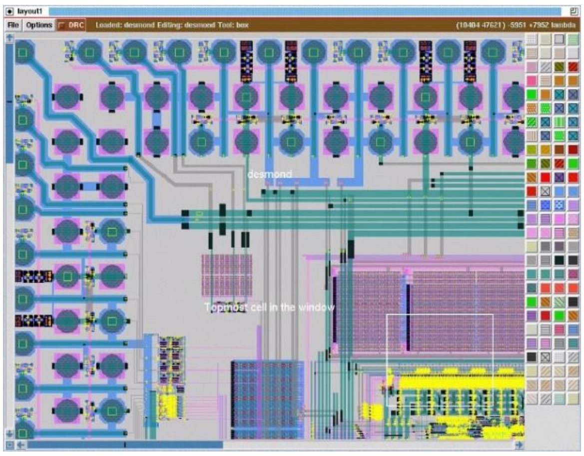

Figure 3. *Graphical interface of Magic* [11]

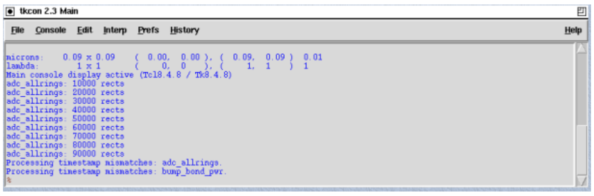

Figure 4. *Command console of Magic* [11]

2.3 Netgen

Netgen is a tool intended for LVS (Layout vs Schematic) verification. The meaning of LVS can be seen in need of verifying physical layout against to schematic representation of the same circuit (Figure 5). Netgen is exclusively used through command console, as shown on figure 6.

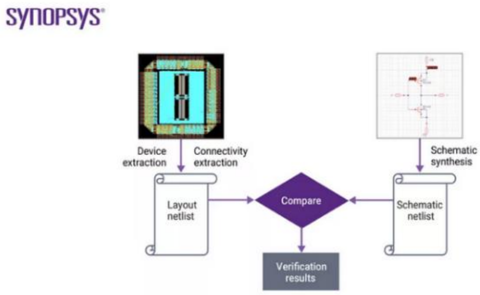

Figure 5. *Process of performing LVS* [12]

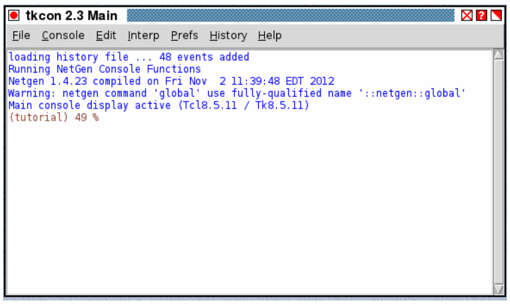

Figure 6. *Command console of Netgen* [13]

2.4 Qflow

Qflow is essentially a set of smaller tools that together fully cover the design of digital integrated circuits from behavioral RTL (Register Transfer Level) design to the GDSII file. The tools that comprise Qflow and their individual purposes are shown in Table 1. Some of these tools are presented in this work as standalone since those tools can be used individually besides being used as part of Qflow toolchain. However, most of the tools used in Qflow are used exclusively as part of the Qflow toolchain. Tools that comprise Qflow are presented in table 1 [14].

Table 1. *Qflow toolchain elements*

Name of Tool	Function
abc	Logic optimization
Magic	Physical layout viewer and editing
Odin-II	Verilog parser and logic verification
graywolf	Placement
qrouter	Detail Router
vesta	Static Timing Analysis
yosys	Verilog parser, HL Synthesis and logic optimization and verification

Qflow is used through GUI control manager, as shown in figure 7.

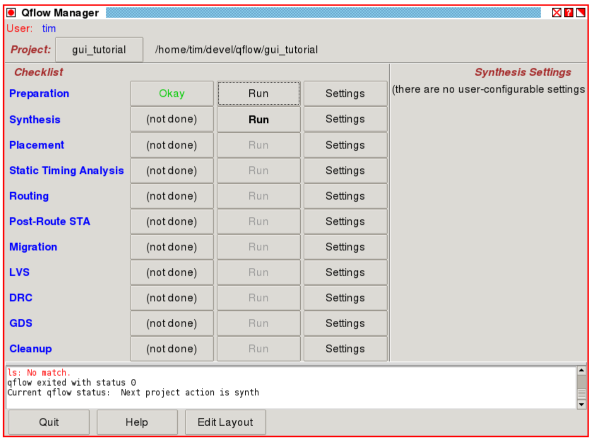

Figure 7. *Qflow GUI control Manager* [14]

2.5 Qrouter

Qrouter is a tool that performs the routing of metal layers with the aim of connecting the submodules (in the most efficient way) that make up the design to be implemented. It is used as part of the Qflow toolchain or as part of another methodology for designing digital integrated circuits, which means it is always part of a toolchain and is used through the command console.

3. METHODOLOGY AND METHODS

The research was conducted in the Laboratory for Computer Science at the Faculty of Technical Sciences in Čačak, University of Kragujevac. Test cases for tool analysis were various digital designs of different levels of complexity. The selection of tools to be analyzed was based on their continuous adherence to and support of the open-source philosophy. The chosen tools fully cover the capabilities required for designing both analog and digital circuits, and the tools analyzed are (1) IRSIM, (2) Magic, (3) Netgen, (4) Qflow, and (5) Qrouter.

All the tools discussed are primarily intended for use on the Linux operating system, with some tools also capable of being installed and used on Windows platforms with few additional installation steps.

The research and data collection were conducted using a combination of different methods, such as functional scenario testing, observation and experimentation. Qualitative data analysis was used for data analysis. The parameters observed and analyzed were grouped into four categories: (1) functionality analysis, (2) user experience analysis, (3) performance analysis, (4) support and documentation analysis.

The combination of results from these analyses provides a comprehensive evaluation of the tools, revealing the quality and efficiency of the tools for integrated circuit design, as well as their advantages and disadvantages. Each of the before mentioned categories consists of several parameters that were analyzed, and the results obtained from the analysis are presented in tabular form.

4. RESULTS

Based on testing of usage and functional value of tools the following analysis results can be obtained.

Table 2. *Analysis of functionality of Open Source tools for IC design*

	Simulation	Circuit Design	Automatic Place and route	Verification
IRSIM	+	-	-	+
Magic	-	+	-	-
Netgen	-	-	-	+
Qflow*	-	-	-	-
Qrouter	-	-	+	-

*It does not contain any capabilities by itself, but instead it connects all necessary tools for digital integrated circuit design in form of toolchain.

In table 2, mentioned tools were tested for their capabilities to perform Simulation, Circuit Design, Automatic Place and Route and Verification.

Table 3. *Analysis of user experience of Open Source tools for IC design*

	Interface	Reliability	Adaptability
IRSIM	GUI/Console	NA*	HIGH
Magic	GUI/Console	HIGH	HIGH
Netgen	Console	NA	HIGH
Qflow	GUI	MODERATE	HIGH
Qrouter	Console	MODERATE	HIGH

*Not applicable

In table 3, user experience aspects of Open Source tools have been tested. For IRSIM and Netgen user experience aspect of reliability cannot be evaluated properly as their reliability of output to user heavily depends on other tools which they are paired with.

Table 4. *Performance analysis of Open Source tools for IC design*

	Speed	Memory requirements	Scalability	Stability
IRSIM	LOW	LOW	NA	HIGH
Magic	NA	LOW	HIGH	HIGH
Netgen	LOW	LOW	NA	HIGH
Qflow	LOW	MODERATE	HIGH	HIGH
Qrouter	LOW	LOW	NA	HIGH

In table 4, performance analysis has been provided for Open Source tools for metrics that can be captured by regular usage of these tools. For few tools, same parameters could not be captured.

Table 5. *Support and documentation analysis for Open Source tool for IC design*

	Documentation	Forums/Community	Video tutorials	Updates
IRSIM	+	+	-	+
Magic	-	+	+	+
Netgen	+	+	-	+
Qflow	+	+	-	+
Qrouter	+	+	-	+

In table 5, learning and support resources availability has been analyzed and it covers all potential resources and materials.

5. DISCUSSION

The results of the conducted research provide information about the characteristics of open source tools for integrated circuit design, defined in four categories: (1) functionality analysis, (2) user experience analysis, (3) performance analysis, (4) support and documentation analysis. The focus is on the context and potential applications for scientific research purposes.

During the research, there were methodological limitations. Specifically, the tools included in the analysis have different roles in integrated circuit design, making it difficult to set analysis criteria that are relevant to every tool. The results of the analysis confirm that, in addition to advantages those tools have for scientific research, there are also disadvantages that could be overcome through professional and scientifically grounded approaches.

One of the advantages of open source tools for IC design identified is the availability of the tools, i.e., free access. In the academic community, one of the prerequisites for using tools is their accessibility, especially since the tool needs to be provided on multiple computers, and universities and institutes have limited financial resources. Using open source tools offers the possibility of accessing new technologies, whose licenses are very expensive when acquired through free market. In this way, the tools would be available to young researchers at the beginning of their scientific careers, or even to doctoral or master's students engaged in scientific research.

Another aspect marked as a significant advantage is the flexibility, i.e., the ability to adapt to specific requirements and needs. In scientific research, this is very important aspect for the development of innovative solutions and the advancement of science, unlike commercial tools that often come with closed code.

Although the official lack of support is a drawback of open source tools, the third characteristic recognized as an advantage is the community created around open source tools. In scientific research, the community gathered around the tools encourages collaboration, which as a result creates environment to exchange of knowledge and ideas and contributes to the advancement of scientific research.

The research results showed that open source tools for integrated circuit design have disadvantages compared to commercial solutions, mostly concerning functionality. While the industry is almost helpless regarding these types of deficiencies and resorts to commercial but reliable solutions for which they are willing to allocate significant financial resources, in the scientific research process, the functional shortcomings of open source tools can be overcome with the knowledge and expertise of researchers using the tools. For young researchers, participation in activities related to the improvement and development of open source tools can be particularly motivating.

6. CONCLUSION

This paper analyzes open source tools for integrated circuit design to explore their potential applications in scientific research. By analyzing five tools with different functions in integrated circuit design, highlighting their advantages and disadvantages, the importance of such solutions for the scientific community is emphasized.

Open source tools for integrated circuit design offer free access, the ability to customize tools to specific needs, and encourage collaboration and knowledge exchange in a research environment. For the academic community, it is important to motivate the development of open source tools for integrated circuit design and their application in scientific research. The use of these tools enforces the principles of open science, enabling greater transparency, mutual benefit, and the promotion of research in integrated circuit design and electronics in general.

Future research can be expanded to investigate functionalities not covered in this analysis. Additional efforts can be made to improve existing shortcomings of such solutions and, finally, consider the possibility of applying these tools in other fields.

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