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Preliminary Design of Reconfigurable Logic Experiential Learning Board for Computer Engineering Research and Education

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***Abstract*- Modern research tracks in computer engineering is benefiting from reconfigurable logic hardware. It allows for rapid prototyping of early-stage concepts in hardware and validate its implementation. However, their manufacturers usually offer complex boards, which may offer components not used. Thus, in this research paper, we offer a preliminary design of a basic reconfigurable logic boards, with only basic components, to minimize its cost. This research targets to utilize lost cost Field Programmable Gate Array (FPGA) devices. A basic printed circuit board design is illustrated in this paper for demonstration purposes. A comparison between comparable board components, and the proposed one is also presented showing a favorable trends towards disseminating this technique to researchers universities in the nation and abroad.**

***Keywords*- Higher education enhancement, Technology in education, Field Programmable Gate Arrays (FPGA)s, Prototype Laboratory development.**

I. INTRODUCTION

Field Programmable Gate Arrays, were introduced in 1985 by Xilinx, but at that time it offered very limited capability and was not so attractive to designers [1], After it was patented in 1992, it was used in a project funded by the US naval surface warfare department to develop reconfigurable logic computer components. From a few hundred configurable components, we have FPGAs that are capable of modeling millions of programmable gates. Its market share today is in the billions of US dollars.

Basic Logic gates are too many to list. But limited input gates, for example two input gates can be useful to illustrate how FPGAs work. Consider a table of two binary inputs, one output. It will have 4 rows listing the 4 possible input combinations (00, 01, 10, 11) ordered this way from top to bottom. Since any binary gate has only one output, the gate can be fully defined if the output is defined for all 4 input values. So, in this table, (i.e., the truth table), we need to assign the output by choosing either a ‘0’ or a ‘1’ in each of the 4 rows. For example, for the 2-input AND gate, the output must be assigned as 0,0,0,1, for the rows ordered from top to bottom. The 2-input OR gate the output assigned as 0,1,1,1, and the output of the XOR gate should be 0,1,1,0 and so on. Thus we can have up to 2^4 total different 2-input gates.

If we are given an integrated circuit that is capable to store these different output assignments in memory cells, and give us the ability to change them later, then we will be using an FPGA technology. The main concept of FPGA technology is its reconfigurable logic using Look-up-tables (LUT). FPGAs can use Static Random Access Memory (SRAM), to store LUT values for various output configurations we chose. Unlike Flash memories, SRAM is known that SRAMS are not vulnerable to wear-out for repeated writing [2]. Memories, i.e. SRAM are volatile, which means they need to stay powered to keep their contents. Even though this might be considered a disadvantage, but actually it allows us to erase contents quickly (i.e., eventually erasing all FPGA configurations) when power is disconnected. Of course, a copy of the configuration can be stored also on Flash memory, and reloaded the next time the power is connected to the FPGA. For beginner designers, educators use this feature as an advantage, since students don’t have to worry too much about making design mistakes. Contents of the memory can be erased, and student can start again quickly, and safely.

Figure 1 shows an example of a Configurable Logic Block CLB of 4 inputs, and two 3-input LUTs, Full-Adder (FA), sequential D-type flip flop (DFF), multiplexers (MUX) with select lines. One of the MUXs select lines is connected to the input d of the CLB, while the other is connected to the CLB sequential/combinational configuration choice to use or bypass the DFF correspondingly.

Actually, FPGA manufactures use SRAMs to allow configurable routing of wires as well. To imagine that, two intersecting wires can be set to connect or be insulated from each other by means of a binary gate to allow them so. Hence, the whole FPGA chip can be configured by knowing exactly what each “bit” needs to be in each wire crossing, and each LUT. This whole group of bits is called the configuration file. The term “Programmable” in FPGA name actually means loading this configuration file to its SRAM, so that it can operate as designed. It is unlike programming a computer in terms of serios of sequential instructions translated to binary code. Once the FPGA gets its configuration file loaded, it does not actually execute a program. It is implementing logic described by those LUTs and connections on its reconfigurable resources.

Figure 2 shows an example of a typical FPGA, with an array of CLBs, and reconfigurable interconnection wires. The modules of General-Purpose Input/Outputs (GPIO) are also of paramount importance, since they configure the mode of each of the pins of the chip to be input, output, bidirectional, buffered, etc. Modern FPGAs are based on the same concept, but they may also offer non-reconfigurable components, such

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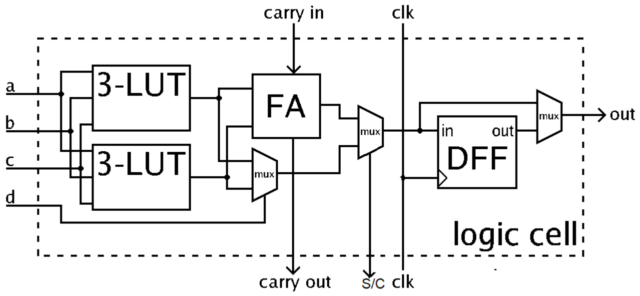


Figure 1: Example Configurable Logic Block of a generic FPGA

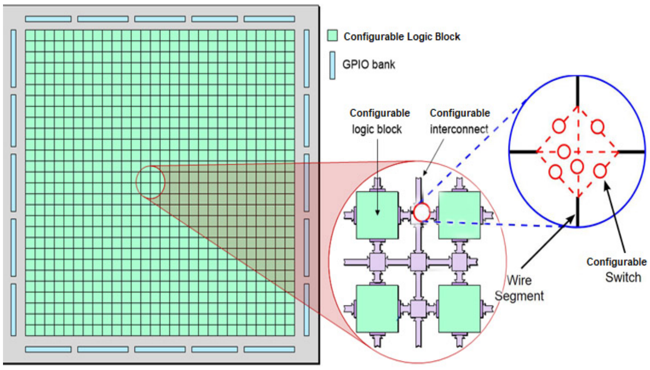


Figure 2: Illustration of a typical FPGA, with an array of CLBs, and reconfigurable interconnection wires via configurable switches

as memory cells, microprocessors, input/output transceivers, and so on.

As mentioned before, digital logic function outputs can be fully defined when we state which binary values are assigned in a LUT format. A two-input LUT can have 16 configurations, but the values of the inputs will be used in any configuration to determine the output. With large number of CLBs, routing resources, and GPIO pins, computer aided design tools (such as Quartus II IDE for inter FPGAs) become a necessity to automate to translation of the design from any hardware description language to a binary output of FPGA configuration. These tools help not only in translating the given logic design into binary configuration file to the FPGA, but they are also very useful in simulating the design, performing time and power calculation, computing chip efficiency and resource utilization, etc. One of such features is shown in Figure 3, for performing a logic circuit simulation with a given test vector to a basic XOR logic gate.

Logic circuit designers are now equipped with sophisticated design tools, which make the FPGA a feasible choice for implementing, testing, evaluating multitude of integrated circuit components. Furthermore, FPGA technology allows designers to use already fabricated integrated circuits to implant logic circuits and changed them later. Thus, FPGAs become a perfect technology for educators who are involved in reconfigurable hardware design courses.

Instructors using Experiential learning need to only show directions of how to accomplish a task, and not giving the learners all the details of how to take the route to the desired destination [3]. Thus, it makes learning an experience (i.e., not just perform an experiment) that moves beyond the classroom instruction and allows students the opportunity to draw conclusions, and being more involved in their own learning process.

Experiential Learning is thus considered as Learning by reflection on Doing [4-12]. It is not a new concept, and various philosophers stressed it in their teachings. It was conceptualized by Aristotle about Ethics as “for the things we have to learn before we can do them, we learn by doing them (first!)” [13]. However, in the 1970s, David A. Kolb developed a fundamental modern model of experiential learning [14]. According to Kolb, [15-16] the learner must be actively involved in the experience; reflect on the experience; analyze the outcomes; and perform decision making and problem-solving skills in order to use the new ideas gained from the prior experience. In this process, instructors to give constructive feedback to the learners, but they should not rush to provide the answer [17-19], especially when creative abilities are to be developed (critical thinking, design, synthesis, etc.), and particularly when there is not a single right answer. They will use their experience to judge or evaluate an outcome of a targeted component and share it with the learners [20-21].

Experiential learning was used in different fields of engineering education. For example [22], it was used via hardware emulators, and FPGA were used in latter stage of complex multi-part designs. Also, in 2020, two different comparative studies for experiential learning were done in two different universities in China, and New Zealand considering virtual reality applications, concluded that it enhances learning experience [23,25]. Furthermore, researchers investigated the incorporation of experiential learning at a Canadian university, in 2017, but they implemented it in a single engineering

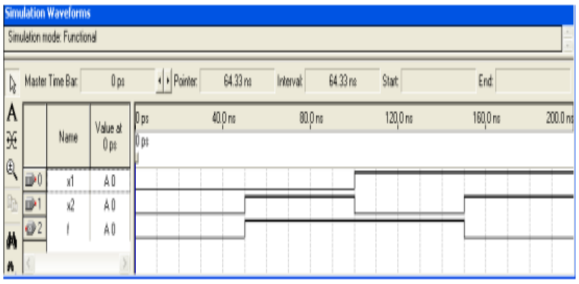


Figure 3: Example of functional simulation to XOR gate using FPGA design tools

course, without FPGAs, and thus results were limited [25]. Recently, a research team in Horus University-Egypt adopted the use of FPGAs in experiential learning [26, 27].

For researcher to use a reconfigurable logic board, they may elect to use the FPGA board, the Altera DE2, shown in Figure 4 [29]. However, this board is not fabricated locally, and may include many components that not necessary for the researcher's needs. Thus, this research paper, we offer a preliminary design of a basic reconfigurable logic boards, with only basic components, to minimize its cost. This research targets to utilize lost cost Field Programmable Gate Array (FPGA) devices.

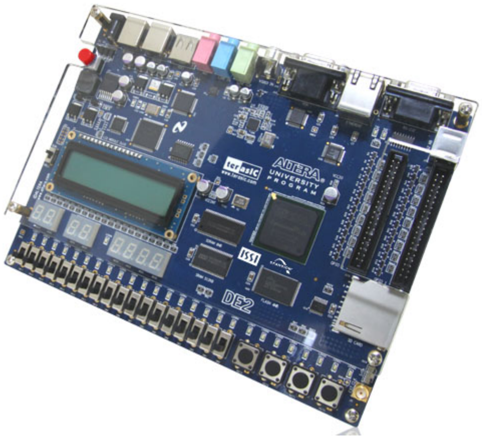


Figure 4: Sample sophisticated Altera DE2 board

II. BASIC BOARD DESIGN AND SAMPLE COMPONENTS

The author founded the Experiential Learning Research Lab in the Faculty of Engineering at Horus University-Egypt via funds made available both internally and externally. Figure 5 shows an angle of this lab, where stations are set to design different students experiences [26, 27].

Figure 5: The Experiential Learning Research Lab (EXL-Research) showing multiple stations

Of the acquired boards, is the Mini-FPGA board (EP2C5), shown in Figure 6. It has 4608 Logic Element (LE), which is similar to CLB mentioned in Section 1, 119,808 RAM bits, 13 embedded multipliers, 2 Phase locked Loops (PLL), and a 158 maximum user input/output pins [28].

For researcher to use a reconfigurable logic board, they may elect to use the FPGA board, the Altera DE2, shown in Figure 10 [29]. However, this board is not fabricated locally, and may include many components that not necessary for the researcher's needs.

Based on a Cyclone II FPGA boards, the instructor may further challenge the students by projects of medium to high complexities. Examples include time multiplexing/switching between inputs of keyboard, or keypad, interfacing to complex peripherals such as analog to digital/digital to analog converts, cameras or LCDs. Thus, students will need to use more capabilities of the FPGA design tools. Also, for advanced courses, the same project can be extended to send the outputs to a network interface, thus using a web browser, and a microprocessor on the FPGA chip and so on. In those later experiences, students will need to learn more about Hardware Description Languages (HDL), such as Verilog or VHDL together with Schematic editors, in-chip logic analyzers, functional simulations, and timing simulations.

Schematic entry is the first step in custom circuit board design. Thus, this paper demonstrates some of the entries made to design a basic FPGA board. Figure 6-A, B, C shows such samples of the schematic entries of the custom board. Then a printed circuit board (PCB) is created from the schematic entries. Figure 7-A, B, C shows different views of the PCB layout. Finally, a bill of board material is created, and the files are given to a manufacture to fabricate it.

III. FPGA BASED EXPERIENTIAL LEARNING COMPARISON WITH CONVENTIONAL METHODS

Conventual ways to implement basic logic circuits include:

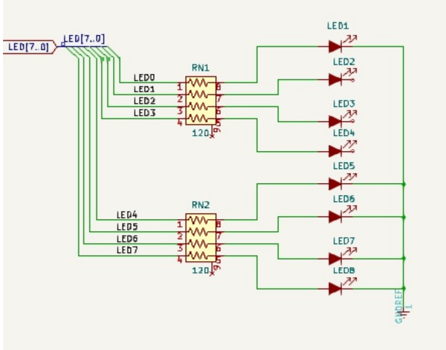


Figure 6: Schematic parts of the custom board, A- LEDs

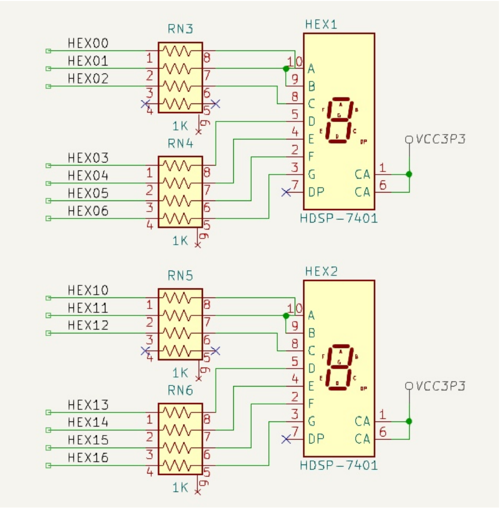


Figure 6: Schematic parts of the custom board, B- Seven-Segments

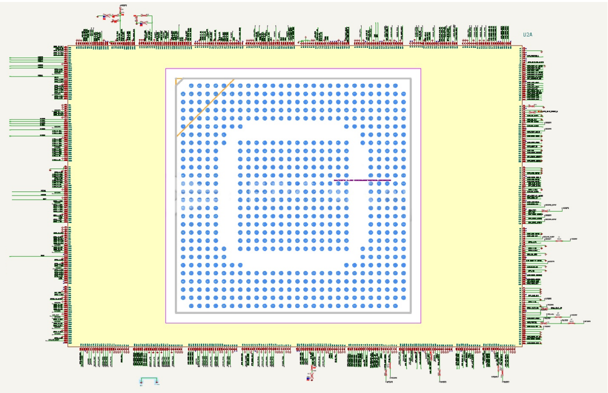


Figure 6: Schematic parts of the custom board, C- FPGA Pins

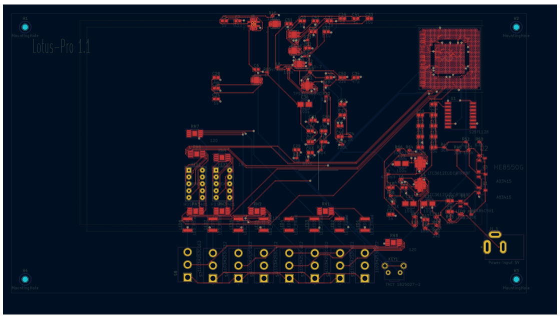
- Logic simulation
- Discrete component implementations
- Ready off-the-shelf logic blocks

Int the following we list advantages and disadvantages of these choices as they compare with

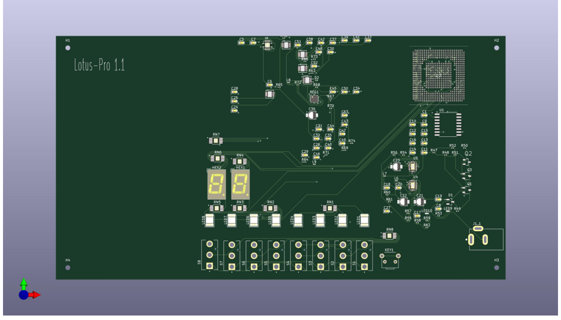
- Modern, FPGA based logic circuit implementations

Logic simulation: This is typically a computer-based simulation of the logic circuits (such as Logisim, Modalism, etc.). Although very useful to illustrate teaching concepts, but they fail to give the necessary physical experiences, and students may still find it not convincing that their design will actually work.

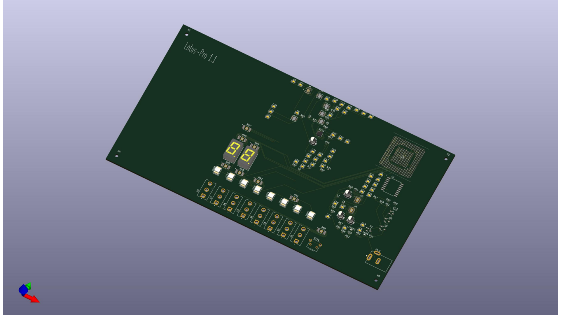
Discrete component implementations: This is straight forward buy, and try approach. Usually, students are asked to acquire parts on their own, and build the circuit. Most of the time, due to lack of prior experiences, students break many parts, and may get frustrated from having to buy more parts to replace failed ones. Also, it requires a very thorough attention to details of all wirings, which can be sometimes too time consuming and also frustrating.



A-Footprint view



B-front view



C-3D view

Figure 7: Proposed Custom PCB layout

Ready off-the-shelf logic blocks: This tries to remedy the problems of previous choice, but for its simplicity, fails to give the student the proper hardware experiences of industrial implementation technology.

Furthermore, none of the implementation methods used above are actually used in the computer logic design industry today.

FPGA technologies have reached a maturity level that is used in industry and can be also used in multi level (i.e., basic to complex) design circuits.

Table 1 shows the bill of materials of the custom board.

Table 1: Bill of Material of the developed board

Component	Quantity
Capacitors	53
Resistors	52
LEDs	10
Slide switches	8
Inductances	8
Transistors	3
Diodes	2
Seven segments	2
Push button	1
Cyclone FPGA	1
Support ICs	9
Total	**149**

This list of components, is much less compared to the components populated in the DE2 board shown in figure 5. Thus, it is expected that the mass production of this custom board will be much less than the DE2 board. It is worth mentioning that the DE2 board is based on Cyclone II FPGA device, which costs less than $30 per chip [31], but the whole board costs 15 to 20 times more in todays market [29].

IV. CONCLUSIONS

In this paper, the we presented a preliminary design of reconfigurable logic board (with about 150 components) for experiential learning to computer engineering researchers, educators, professionals, and learners. Furthermore, we compared such proposed board with an existing board, showing that the developed could potentially reduce the cost of its manufacturing, helping in the sustainability of research in this field.

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Conflicts of Interest:

All authors declare that they have no conflict of interest regarding this research paper and that they comply with research ethics.

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