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Current challenges and opportunities in computation and simulation to align 4iR paradigm shift

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ABSTRACT

With the advent of 4th Industrial Revolution (4iR or Industry 4.0), the current industry sector is highly automated to increased productivity, flexibility, and quality of products & services. The technology, machinery, materials, inputs, and approaches are radically transforming in the traditional manufacturing companies using several enabling technologies, tools, and systems in this digitization era. Industry 4.0 is the game changer to the end of the conventional applications where computation and simulation play a pivotal role in forecasting and evaluating methodically intractable systems' performance. In this paper, the authors describe the prominence of computation and simulation technology in this industrial transformation and analyze the current challenges and opportunities of computational simulation technologies and tools to uphold the effectiveness.

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1. INTRODUCTION

Since last few years, most of the industries, whether it is manufacturing or services have improved the productivity, product quality, and mechanism of operations using innovative technologies [1]. It is because modern industries are experiencing change and development toward complete digitization and production intelligence to attain high efficiency [2]. The industry which started with 1st revolution with the steam-power and mechanized system in 1784 followed by 2nd revolution and 3rd revolution with mass production and electrical automation, respectively has now entered into 4th revolution. Figure 1 shows the navigation of this Industrial Revolution [3].

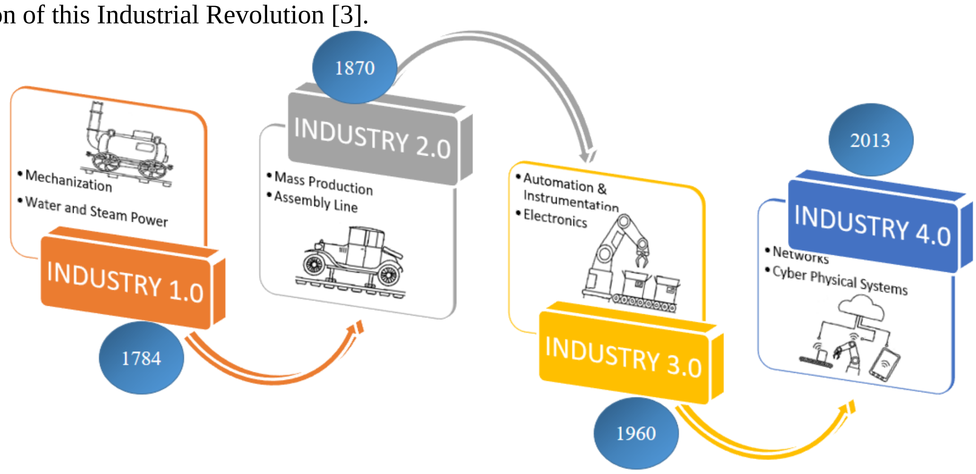

Figure 1. Navigation of Industrial Revolutions

Unlike previous industrial revolutions, Industry 4.0 depends on the idea of smart factories, where the human and machines are integrated from end to end cyber-physical systems (CPS). There are nine new categories: big data, cloud computing, cybersecurity, Automated robots, additive manufacturing, 3D printing, augmented reality, Internet of things, and simulation, which are the key enabling technologies of Industry 4.0 [3, 4] shown in Figure 2.

Table 1. Reason and effects of industrial transformation

Industrial Revolution	**I1.0 (1750- mid-1800s)**	**I2.0 (1870- 1914)**	**I3.0 (1970- 2011)**	**I4.0 (2011 onwards)**
Reasons and origin	Power generation by **water** such as steam engine	• Evolution of **electricity** • Electrical operated motors	• Programmable device • Electronic device and circuits • Supervisory control using electronics • Information and communication control using **Digital systems**	• Cyber-Physical systems • Advanced automation • Artificial intelligence • Industrial Internet of Things (IIoT), smart • manufacturing and factory
Effects	Mechanized production, Iron and textile industries	Mass production, steel making process large-scale machining and tool manufacturing	Man-machine interface and control in manufacturing, autonomous production	autonomous manufacturing, connected business

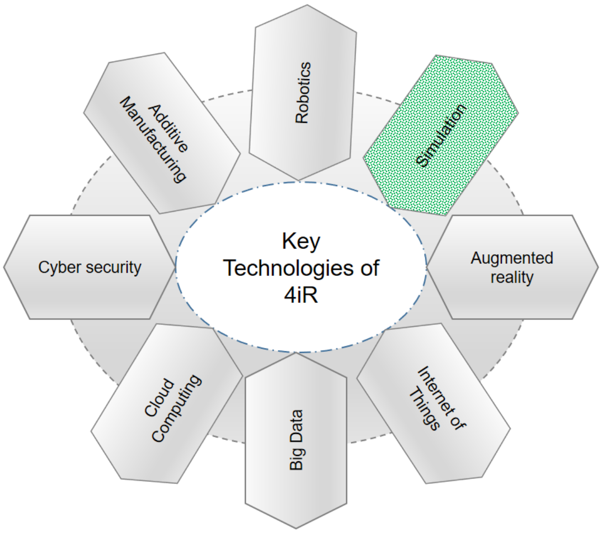

Figure 2. Enabling technologies of Industry 4.0.

Since Industry 4.0 represents entirely new ways of enabling technologies surrounded within societies and even our human bodies, an immediate question is how the university delivers the new set of skills and knowledge required in the era. The simulation and modeling are the foundation technology in product manufacturing in industry 4.0. In the engineering Industry, simulation, and modeling help reduce costs, curtailing development cycles, increasing product quality, and facilitating knowledge management [5, 6].

Table 1 shows the major causes and the effects of industrial transformation spread over a long period [7]. Computer simulation is essential to most Industry 4.0 notions and technologies such as hybrid modeling and simulation, simulation training, data-prescriptive analysis using computer simulation, scheming connectivity, network simulation, and simulation-based product design. Simulation plays a crucial role in comprehending the vision of Industry 4.0, and it would not be inappropriate to refer to the simulation as the heart of Industry 4.0.

2. RESEARCH METHOD

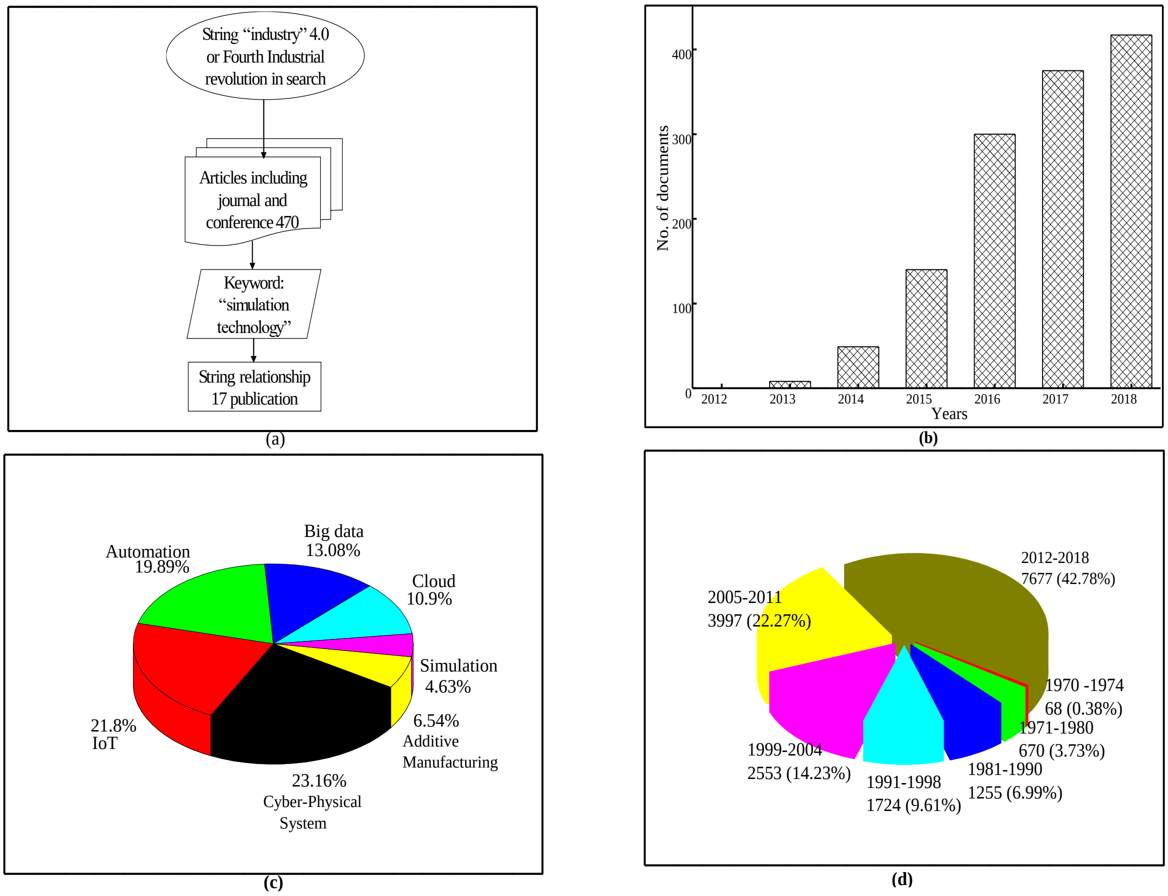

Figure 3. Literature review in this work (a) research methodology (b) no. of documents publication year wise on 4iR/industry 4.0 and fourth Industrial Revolution (c) Industry 4.0 enabling technology publication (d)"simulation technology" string search documents from the year 1970.

The keyword string of "industry" 4.0 and Fourth Industrial Revolution and/4iR was searched in Scopus/google scholar standard database for procuring documentation (articles, conferences, and chapters) for 2012- December 2018 1760 results. Other keyword refined for "simulation technology/tool" resulted in 17 publications in Scopus database that used in this work for the analysis. The analysis indicated 71% of the considered article mention engineering concerns, 44.4% refers to communications matters, and 18.4% were related to business process management. 470 articles found in the search were more refined using 3 specific keywords to characterize "simulation technology".

3. SIMULATION AND CONCEPTS OF INDUSTRY 4.0

Simulation is the technique of using real or hypothetic models of a system/process to analyze and predict the behavior of the system/process [8]. The phenomenal advantages and associated disadvantages of computation and simulation are listed in Table 2.

Simulations are computer-based solutions to create an analog representation using physical and mathematical definitions of the problem. The simulation methodology empowers current manufacturing industries to efficiently execute their plant and processes with optimal resources and enhance throughput [9, 10]. Usually, the computer simulation technique models a real situation and performs experiments on the model or/and developing a computer program that solves the mathematical description of the model to analyze the behavior of the system under certain conditions.

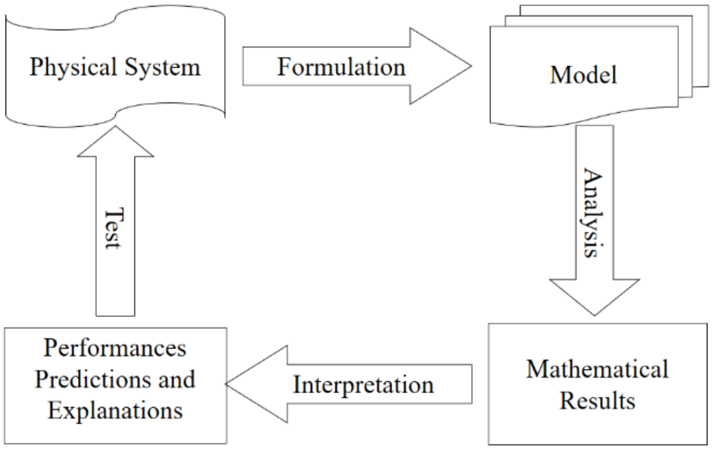

Figure 4. Process of developing a typical model [11].

The procedure for creating a typical physical or mathematical model is shown in Figure 4. The first and foremost step is to identify the modeling purpose and involve the simple assumptions, parameters of interest from the model, identification of numerical methods for analysis, computational facilities, proper optimization, and verification. However, a conciliation between an oversimplified model and a comprehensive model is chosen to avoid the cumbrous implementation of a detailed model or simulation.

Table 2. Advantages and disadvantages of computer simulation.

Advantages	Disadvantages
• can be used to compress a time frame to study the effects of a change in a real-life situation that take place over several years	• poor understanding of the physical operation and results in insufficient knowledge to produce a mathematical model.
• Appropriate for studies that involve complex systems and difficult to derive manually	• fast processor-based computer systems are essential to simulate complex problems
• Useful in designing engineering and product to investigate the effect of modifications without producing a physical prototype.	• requires large amounts of memory for complicated simulations.
• can investigate the conditions that would be dangerous in real life.	• creating simulations to accurately predict the disastrous occurrence are not possible e.g., effects of earthquakes and tsunami.

3.1. Perception of computation and simulation in the past Industrial Revolutions

The history of computer simulations can be traced long back in the 1950s with the need for analysis of random and stochastic processes [12]. The sophisticated design problems were being first solved using simulations in steel and aerospace companies. However, those solutions involved complicated models and well-trained professionals on mainframe computers. Early simulators codes were written on General Purpose codes such as FORTRAN, GPSS, and SIMSCRIPT for building simulation models and based on Discrete Event Simulation (DES) [13, 14].

The simulations use spread had started with the Third Industrial Revolution, in the late 1970s and early 1980s. Those simulation courses at that time had limited graphical representations and mostly text or mathematical based practices. The evolution of computer graphics had revolutionized the computer simulations with the amalgamation of animation and expanded as the decision-making tool.

Later, in the early 1990s, the Graphical User Interface (GUI) made it possible to run simulations on personal computers, which has been a notable milestone in the history of modeling. The building of simulation models involved two-dimensional iconic and drag-drop approach for object modeling [15]. In present scenario, there are several simulation tools available. A good source for a list of simulation tools can be found at https://www.capterra.com/simulation-software. Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) with a detailed 3D view and DES are now an integral part of design and manufacturing and evolving the foundation of 4iR.

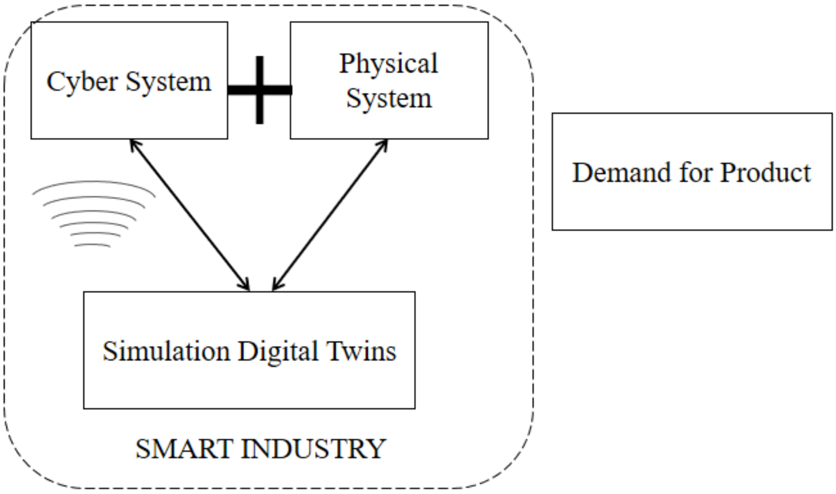

Figure 5. Cyber-Physical Systems and simulation [16].

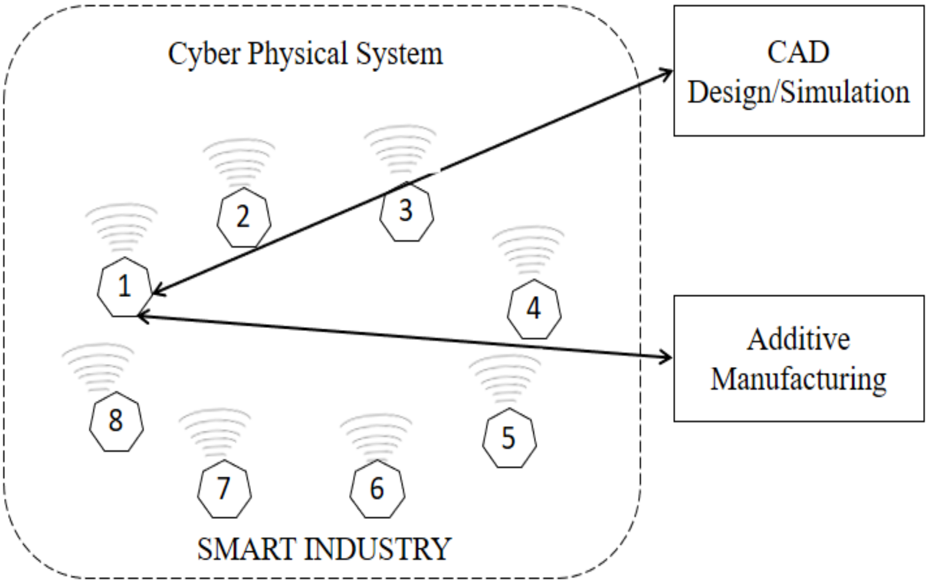

Figure 6. Additive manufacturing and simulation.

Additive manufacturing is a collective term used for making 3D objects by adding forming material layer-over-layer. The CAD software, to design the object and the layer arranging device to create the structure, are the two critical elements in additive manufacturing for Industry 4.0 as shown in Figure 5 and Figure 6 [17].

4. CHALLENGES WITH SIMULATION METHODS IN THE INDUSTRY 4.0 ERA

The fourth industrial revolution carries new prospects to realize smarter manufacturing. Individually transport, machine, or workplace can be self-governing to control and regulate themselves. The instantaneous data collected from the sensors of the tools can be used to avoid defects or indemnities appropriately. Innovative man-machine interfaces and 3D printing techniques can accelerate the transformation of digital instructions into the real product. The features of Industry 4.0 can significantly increase productivity in a factory or a supply chain. Table 3 lists the significant limitations of each type of simulation, enabling technology that restrain their use in the fourth industrial transformation scenario.

Table 3. Challenges and limitations of simulation technologies in fourth industrial transformation

Simulation technology	Challenges and Limitations		
Computer-Aided Design (CAD)	• tools complexity of menu items or commands • usability	• interactive assistance during the designing • integration of casual and informal conceptual design tools	• inadequate human–computer interface design • fixation on design routines [18]
Computer-Aided Process Planning (CAPP)	• responsiveness and adaptability to the modifications in the production capacity and functionality	• incapability of adjusting to dynamic operations and a process plan • integration of casual and informal conceptual design tools	• sometime take unreasonably extra time and effort [19]
Computer-Aided Manufacturing (CAM)	• need focus on collaborative techniques	• effective communication • requires efficient data exchange [20].	• analysis is to be acquired using software agents and agent societies [23, 24] • Methodologies with a provision of knowledge management
Process Simulation	• integration of planning, data transfer and optimization of manufacturing process chains into a standard model.	• efficient simulation-model generation to allow the user to accelerate the process of producing correct simulation models [22].	• simplified simulation-model generation to process credible simulation [22]
Supervisory Control and Data Acquisition (SCADA)	• SCADA systems are generally designed to be dependable and fail-safe	• standards to avoid and address security breaches to adequately consider the risks of a deliberate attack.	• increased connectivity and the loss of separation between SCADA and other parts of IT infrastructures of organizations [21]
Supply Chain Simulation	• identifying the gains of collaboration is a challenge for many situation in supply chains [26]	• misperception among the optimum number of partners results inaccurate computation	• investment in collaboration and duration of the partnership are some of the obstructions of healthy collaborative engagements that should be surpassed [25]
Manufacturing Systems and Networks Planning and Control (MSNPC))	• the prevailing technology does not tackle the recurrent issues of manufacturing network management in integrated holistic way [27]	• produces contradiction in the results of distinct modules owing to their indirect manufacturing information and context procedure.	• The coordination between input /output level and the actual information contents are often neglected that obstructs applicability of the tool in real-manufacturing systems [28]

Besides the limitations and challenges associated with the technological simulation tool, other future challenges exist. First of all, simulation tool developers are progressively announcing cloud-based technologies to provide the mobility and operational compatibility to the applications in this phase of industrial transformation while only limited commercial tools have integrated this function. Furthermore, the complex processes entail high-performance simulations that in turn necessitate the costlier and powerful CPUs [29, 30].

The application that runs in multiple and mobile devices need extended use of open and cloud-based tools. The current software tools deal only with limited application based object libraries. There are minimal functions and resources included in the majority of tools. Due to the unavailability of an integrated framework, incorrect data exchange cause difficulties partnership among systems. The issues could be resolved using incorporating multi-disciplinary-domain tools. The direct incorporation of tools with CAD, DBMS (such as ORACLE, SQL Server, Access) [31], direct spreadsheet link in/out, XML save format, HTML are limited up till now. Though slight efforts and initiatives have been taken to adopt the concept and the models of the smart factory, however, the technologies related to the virtual factory, acquisition, control, and monitoring are sluggish in their initial stages, costly, complicated, and inflexible to apply. Therefore, additional efforts are required to develop smart, intelligent, and auto-learning implements.

5. SIMULATION OPPORTUNITIES IN ELECTRONIC INDUSTRY 4.0

In developing electronic products in industries, simulations are extensively used to prototype design and analyze the performance before physical implementation. The widespread application of an electronic product depends on device physics and the performance of elementary components, circuits, processes, and control systems. Upcoming electronic engineers need to have the skill and work experience of dealing with simulation methodology to align with Industry 4.0 and future employability prospects. Electronics engineering is among the dynamic fields of scientific study that has been progressively growing to solve the world's difficulties through quicker, low-cost optimal solutions. In this context, models and simulation packages are intended to help engineering researchers to a greater extent [32-34].

Unfortunately, not much attention has been given to training and skill development on modeling and simulation technology in the current educational system except the initial introduction of simulations based learning. Academic curriculum in most of the Universities and technical institutions that offer higher engineering education does not include broad coverage of modeling and simulation techniques. Also, the available simulation course contents are mostly beyond the Industry 4.0 needs. For instance, the authors using their experimentation of device simulation, describe how the implementation of the simulation study for electronics education would be in-line with the context of work-integrated learning in the era of industry 4.0. The simulations are based on the modeling that mathematically describes predicting a physical system's output in the operational range.

5.1. Work Integrated Learning and simulation

Work-Integrated Learning (WIL) is career-focused learning that integrates theoretical and practical knowledge acquisition at university and industrial workplaces [35]. A study by N. Wilton and Salm et al. showed the role of WIL in extending the student's competencies reported enhancements in employability and skills and the procurement of professional competencies in practicum [36, 37]. The qualification develops the ability and attitude to apply skills at curious aspects. Therefore, a graduate would be expected to perform a professional task in the years of employment.

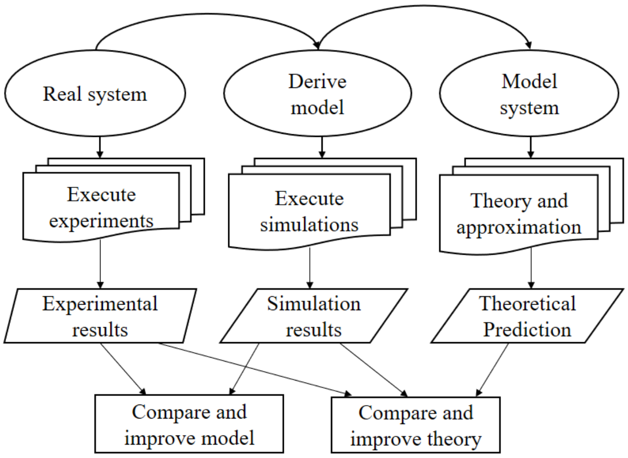

Figure 7. Simulation procedure in electronics industrial transformation.

The simulation often involves an understanding of creating methods and mechanisms of specific dimensions, execution, coding and designing, extraction of output, and to inspect and rigorous analysis of results for a novel device simulation in electronics. In the simulation process, knowledge of coding and designing are required depending on the type of technologies. Figure 7 shows the simulation procedure in electronics device simulations for predicting the device output and Figure 8 shows the author's simulation works on the research question of improvement in Active Matrix Organic Light Emitting Diode (AMOLED) and Active Matrix-Liquid Crystal Diode (AMLCD) pixel circuit of smart displays [38-40]. The device has been thought of with specific dimensions and created using the device simulator platform. In this exercise, improvement in simulation results could be discovered without the long fabrication cycle and cost.

Simulation technologies have capabilities of analyzing, extracting the device results and incorporating them into the applications. Almost similar skills are needed for circuit and process simulations.

Industry 4.0 is based on manufacturing various device, circuit and process using simulations. The production in electronic industries requires skilled simulation designers due to other technology integration in 4iR.

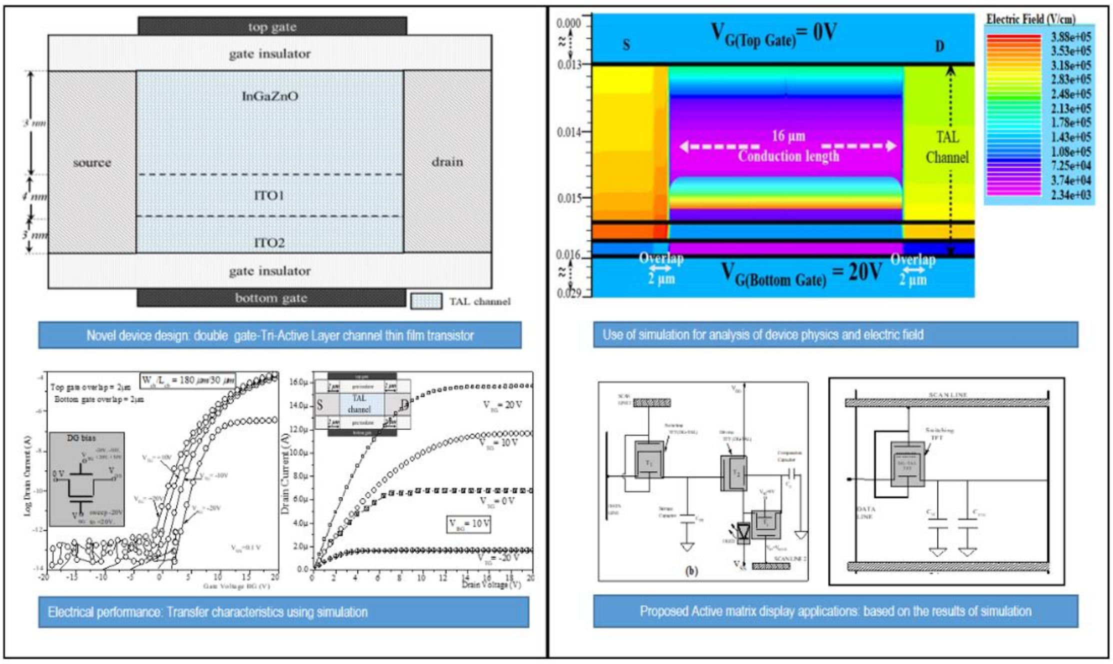

Figure 8. Use of Simulation method to explore devices for AMOLED and AMLCD display applications

5.2. Work Integrated Learning Modalities for Simulation Skills Development

The previous section explains the importance of simulation skills for future electronics employees; the authors propose incorporating an emphasis on developing those skills with the current WIL method. The courses on simulation tools currently in use by the industries must be included in the Universities and Technical Institutions' academic curriculum. The Work Integrated Learning, which allows student learning at both industry and academic institutions, needs to join hands for simulation skill development. The courses on learning the simulation by the industry experts before industrial exposure seem the right solution.

The University or Academic Institution can plan the simulation skill courses in connection with the Industry 4.0 needs. The work industry can provide design challenges, related tasks, and projects for the students. The pedagogical practices and execution of work-related tasks in the classroom can be synchronized.

The industry-standard simulation tool developer and academic institution partnership can be encouraging for procuring tools and accessibility. The concept of simulation that emerged in the third industrial revolution is a big player and a very significant driver in the fourth revolution's progress. The current revolution imposes the learning of electronics to be redefined with emphasis on the modeling and simulation skills.

a) There should be early exposure to the significance of system modeling and simulation in engineering to undergraduate students to enable them employable in the era of 4iR.
b) Postgraduate studies and research in electronics engineering should be more focused on using simulations in the relevant electronics engineering study field.
c) Technical discussions among the students should be encouraged, fostering novel simulation-based solutions to the engineering problems. Training workshops and seminars should be organized by institutions to train technical staff in pertinent simulation packages.
d) Simulation software developer and universities need to strongly affiliate to find out access of industry used versions of the tools at affordable subsidized prices for educational purposes—also, the professional training of lecturers in engineering on how to use simulation packages.
e) The university/institution libraries should be stocked with updates modelling and simulation kinds of literature.

f) Fabrication or manufacturing industry to provide problem assignments on current engineering projects for simulation under WIL learning program and hands-on training of equipment for the experimental fabrication of the project.

6. CONCLUSION

The fourth industrial revolution intends numerous unprecedented opportunities for a paradigm shift. It facilitates the vision and execution of intelligent automation and enables faster, more flexible, and more efficient processes to reduce costs, produce higher quality goods, and enhance customer service. As a result, it has a fundamental impact on the competitiveness of companies and regions globally.

The computation and simulation would continue as the prime constituent for the industries to benefit from the fourth industrial paradigm. It would provide higher opportunities for industries to increase productivity and the economy and skilled simulation engineers. The sophisticated outlines used in the current design phases are increasing and involve high skill and long processing time that do not facilitate crowdsourcing. The academic acceptance of simulation skill development would result in sustainable growth in more job opportunities. Innovative man-machine interfaces and 3D printing techniques can accelerate the transformation of digital instructions to the real product [41, 42]. The current WIL method would significantly impact with the emphasis on simulation skill development for future engineers and socio-economic sustainability. The research and development using newer simulation tools and technologies would be aspiring to the future for the advancement of human living. Last but not least, the challenges associated with organizing simulation technologies tool and skill including the availability of costly platforms, training, academic alignment, can overcome by the academia-industry partnership. In conclusion, there has been a significant evolution of simulation tools in the past, and remains a fertile research field.

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