Impacts of the Fourth-Industrial Revolution and COVID-19 Pandemic on the Design of Educational Spaces in Universities

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Abstract

The world witnessed various industrial revolutions that led to the emergence of a new generation of universities. The Fourth Industrial Revolution (4IR) is characterized by speed and technologies that combine material, digital, and biological worlds. Due to the emergence of COVID-19 in late 2019, which was declared a global pandemic by the WHO in 2020, most if not all education learning services are affected. Some universities started utilizing the 4IR technologies to mitigate the impacts of the COVID-19 pandemic. The educational spaces within universities are accordingly impacted. This paves the road for new educational activities and concepts to utilize some of the 4IR technologies such as Internet of Things, and Virtual and Augmented Reality. This paper identifies the expected impacts of 4IR technologies on the design of educational spaces in the 4th generation universities including the impact of COVID-19 pandemic. Comprehensive and comparative analyses are conducted to forecast the expected impacts on educational spaces based on latest literature to transform existing universities to 4G universities. Some concepts are expected to have a strong impact on transforming existing universities to 4G universities. The emergence of the COVID-19 Pandemic has affected the acceleration level of adopting some of these 4IR concepts.

Keywords: COVID-19 Impacts, Educational Spaces, 4th Generation Universities, 4IR.

1. Introduction

In today's world, there are various sophisticated dynamics immersed in different social, cultural, economic, technological, and demographic processes; such dynamics entail many changes including higher education. This led to a gap between labor market needs and delivered education and, consequently, lowering the stature of education and learning. Therefore, universities encounter many challenges on their way for overcoming this gap. Over the years, transformation of universities – from one generation to another – started at all levels: social, cultural, and economic *(Lapteva & Efimov, 2016).*

The world went through a series of industrial revolutions as shown in Fig (1), starting from the **First Industrial Revolution** focused on steam machines for production. Then, in the **Second Industrial Revolution** electrical power was used for production. The **Third Industrial Revolution** started with the advent of computers and internet and used in production, starting the Digital Revolution where in resources, social networks, and web technologies were utilized. Accordingly, Knowledge-based economy has emerged and contributed to social and economic development. Recently, the **Fourth Industrial Revolution** is focusing on digitalization and automation of manufacturing processes with advanced technologies such as IoTs, robots, artificial intelligence, etc. This requires universities' participation in social and economic development for adapting to these technologies for enhancing their competitive innovations *(Abu Labhanm 2019; Schwab, 2016).* The remainder of this paper includes analysis of related literature, research methodology, finding and analysis, discussion and conclusion.

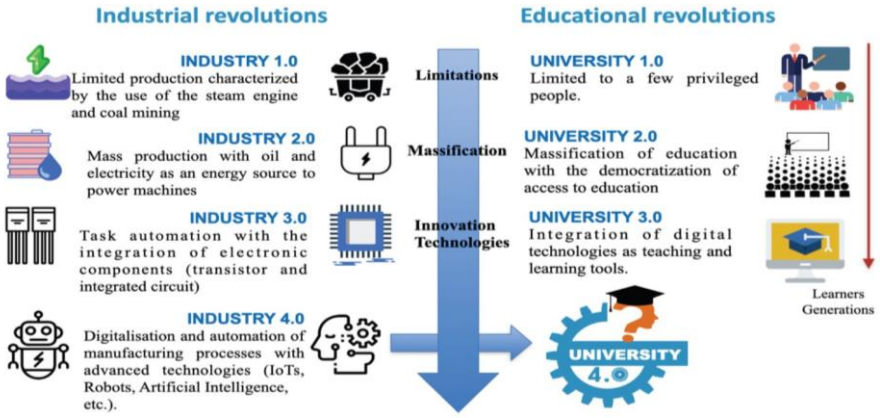

Fig (1) The relationship between industrial revolutions and Universities Generations *(Gueye & Exposito, 2020)*

There are some basic features for each generation as illustrated in Table (1) representing the extent of change in relation to each industrial revolution.

Table (1) Comparison between different generations of universities *(Abu Labhanm 2019; Steinbuch, 2016)*

	1st Generation	2nd Generation	3rd Generation	4th Generation
Objective	Education	Education & Research	Education & Research & Know-How Exploitation	Education & Open Innovation (Research)
Role	Defending the Truth	Discovering Nature	Create Value	Enabling Value Creation
Role of Teacher	Source of Knowledge	Guide and Source of Knowledge	Facilitator and Coordinator of Knowledge Production	Prompt and Facilitator
Role of Student	Recipient	Beginning of Active Learning Process	Active and Participant	Creative and Innovative
Method of Learning	Scholastic	Mono-disciplinary	Inter-disciplinary	Multi-Actor Innovation
Human Capital Development	Professionals	Professionals and Scientists	Professionals, Scientists, Entrepreneurs	Professionals, Scientists, Entrepreneurs, Artist, Customers, Ecosystem Participants
Infrastructure	Classrooms	Classrooms and Spaces Designed for Student Activities	Infrastructure and Technology	Advanced Digital Infrastructure
Orientation	Universal	National	Global	Ecosystem
Technology	Paper University	Paper University	Computers and Internet	IoT
Finance	Government Support and Community Donations	Government Support	Government Support, Tuition Fees, and Projects	Self-Resources
Language	Latin	National Languages	English	English
Organization	Colleges	Faculties	Institutes and Centers	Innovation Spaces
Management	Rector / Chancellor	Part-time Academics	Professional Management	Disruptors

2. Analysis of Related Literature

2.1. Concepts of the 4th Industrial Revolution

With the emergence of the 4th Industrial Revolution, several concepts emerged as shown in Table (2) with new forms of cooperation between man and machines. Such forms of cooperation aid in automation of manufacturing processes and digitization using advanced technologies.

Table (2) Concepts of the 4th Industrial Revolution
(Gueye & Exposito, 2020; Yamao & Lescono, 2020; Hurwitz & Kirsch, 2018; Abu Labhan, 2019; Javid et. Al., 2020; Fong et. Al., 2018; Mihajlovic, 2019)

1	**Cyber-Physical System (CPS)**
	Merging various processes during contact using modern technologies, particularly the internet.
2	**Machine Learning**
	A form of artificial intelligence that enables systems to learn from data, instead of direct programming, as well as pattern recognition and decision-making with the least possible human intervention.
3	**Cloud Computing**
	Providing different services over the internet and handling problems of remote storage of big data.
4	**Internet of Things (IoT)**
	Information infrastructure where the intelligent components – devices, software, and engines – are linked to the communication network; allowing information collection, exchange, and control.
5	**Big Data**
	Large diverse amounts of information that grow at continuous and steady rates in terms of size speed and diversity.
6	**Augmented Reality (AR)**
	Virtual elements are merged with surrounding physical environments to obtain a mixed reality.
7	**Virtual Reality (VR)**
	A simulation constructed by computer where a person can interact in a 3D artificial environment using electronic devices.
8	**Holography**
	A photographic recording of a light field and displaying it in three dimensional images.
9	**Robots**
	Automatically operated machines that perform human activities and work without external intervention for extended durations.
10	**3D Printing**
	Manufacturing and printing elements digital format to physical forms.
11	**3D Scanning**
	Analyzing real-world objects, for collecting data to reconstruct its form and shape in digital form. Thus, the object becomes a 3D model.
12	**Mobile Computing**
	A group of information technologies, products, services, strategies, and operating procedures that enable users to connect and communicate while moving.
13	**Biosensor**
	An analytic device that involves a biological substance (tissue, organisms, anti-bodies, natural products, cell-receptors, enzymes, and nuclear acids).
14	**Biometrics**
	Physical/ behavioral human characteristics that can be used to digitally identify a person to grant access to systems, devices, or data.
15	**Digital Fabrication**
	A manufacturing process using machines, where digital data leads- using computers – the manufacturing equipment to make different geometric shapes and forms.
16	**Computer Vision**
	In this discipline, computers are trained to interpret and understand the visual world, using digital input; to enable machines to identify and classify objects accurately and then, interact.

2.2. Potential Impacts of the 4th Industrial Revolution on Universities and its Educational Spaces Design

The Fourth Industrial Revolution (4IR) is characterized by speed and technologies that combine physical, digital, and biological disciplines *(Abdulrahim & Mabrouk, 2020).* The concept of the 4IR is expected to impact universities. Universities are huge institutions that embrace various elements with reciprocal effects such as users, spaces, activities. All of these are expected to be impacted, when 4IR concepts are applied. The main universities spaces are educational whether inside buildings or outdoor open spaces. They are used to perform the university function. The expected impacts of the 4IR are as follows:

- Teaching and learning, merge the **culture of entrepreneurship and investment** in curricula. It is also expected to impact the form of educational spaces and change the aims and expectations of graduates.
- Students will be impacted through **acquiring new skills**, by working in a virtual/ mixed team, as well as increasing their abilities to solve problems, build projects, etc. This would lead to changing the traditional shape of learning environments within universities.
- The emergence of **inter/multidisciplinary** trends would lead to the creation of new, innovative, educational spaces which were not previously introduced; students can now select educational goals out of a variety of educational programs and break free from the old constraints.
- The emergence of **new teaching methods** such as learning through games, project-based learning, e-learning, blended learning, etc. would impact the shape of educational spaces within universities.

2.3. COVID-19 Pandemic and its impact of the future of Universities and its Educational Spaces Design

The global impact of COVID-19 is multi-faceted; clearly shown in almost all sectors, particularly health, economic, and educational sectors. Governmental procedures have one common goal: reducing COVID-19 outbreak through introducing measures for limiting social contact. This resulted in reducing traditional classrooms to protect students, and the entire society, from the pandemic outbreak. Traditional classrooms are replaced by electronic educational platforms for interaction among students and teachers *(Osman, 2020; Gonzalez, 2020)*. In a very short time, the COVID-19 pandemic has widely enhanced the role of distance learning, e-learning, video conferences, and other similar means. In addition, mobile learning has become an appropriate alternative for students with less technological resources. *(Gonzalez, 2020)*

Within this scenario, university classrooms will not be the same as before, nor would be the campus or its spaces. Although distance teaching in emergency cases was introduced abruptly in the beginning as a safety and security precaution for social protection; it would eventually change the learning scene within universities. So, merits of the current experience must be contemplated to make universities more prepared for the possibility of extending e-learning and distance learning. Experts expect that distance learning will continue to grow and increase the exploitations of distance learning methods. The emergence of 5G technology will support more of mobile learning and open the door to utilizing various 4IR concepts in learning such as IoT, VR, and AR *(Osman, 2020; Zamar et. Al, 2020; Lewis, 2021).* These opportunities are expected to impact educational spaces within universities whereby students can participate in their lectures and lessons from anywhere, without being bound to any specific education physical spaces. So, the method of education in traditional

auditoriums and classrooms will change. The COVID-19 pandemic has also opened new doors for attending workshops and virtual experiments with other universities and opened new routes for students' participation. So, universities will need to redesign educational spaces in terms of function, and introduce various modern technologies needed to keep pace with this digital transformation.

3. Research Methodology

To achieve the main objective of this paper, the following research methodology is adopted. The primary components related to educational spaces and affected by concepts of the 4IR are articulated including people (P), Activities (A) and Spaces (S). Then, an extensive literature review is conducted to identify the most relevant concepts of the 4IR in relation to educational spaces in universities to qualify these universities to 4G universities. Then, the potential impacts of 4IR concepts on people, activities and educational spaces are forecasted based on related literature addressed these issues. Accordingly, a mapping of the levels of expected impacts of each 4IR concepts to each of the educational spaces is developed. In response to the rapid move towards digital transformation during COVID-19, the expected impacts of 4IR concepts in this context on educational spaces are forecasted.

4. Findings and Analysis

4.1. Interrelationships between 4IR concepts and people, activities and spaces in universities.

For existing universities to reach 4G, there is a need to accomplish some requirements in several aspects such as: curricula, teaching methods, learning environments, educational spaces, educational tools, the built environment, infrastructure, technology, as well as legal and financial aspects. This paper focuses on the educational spaces in universities.

In order to identify the expected impacts of the 4IR concepts on universities, its interrelationships with people, activities and spaces are thoroughly investigated. Fig (2) presents the interrelationships as the means to realize the educational spaces in 4G universities.

- Architecture and Urban Spaces (S)
- People (P)
- Activities (A)
- Concepts of Fourth Industrial Revolution (C)

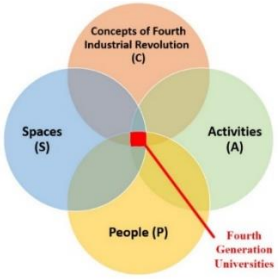

Fig (2) Components contributing to the educational spaces of the 4G Universities

Based on extensive analysis of related literature, a set of concepts of the 4IR that has direct impact on transforming existing universities to the 4G universities are extracted and illustrated in Fig (3). Furthermore, university spaces are articulated into two categories: urban and build spaces as shown in Table (3). People using the spaces includes:

- Students (P1)
- Faculty Members (P2)
- Employees (P3)
- Management (P4)
- Graduates (P5)
- Visitors (P6)
- Parents (P7)
- Staff (P8)

Table (3) University Spaces									
Urban Spaces				**Build Spaces**					
Education		**Public**		**Services**		**Administration**		**Education**	
Outdoor learning spaces	SU_E1	Open Green Area	SU_P1	Gallery	SA_S1	Rooms for Teachers	SA_A1	Classrooms	SA_E1
		Student clubs	SU_P2	Study halls	SA_S2			auditoriums	SA_E2
Open theater	SU_E2	Playgrounds	SU_P3	Reception	SA_S3	Adm. Rooms in Departments	SA_A2	Symposia & show rooms	SA_E3
		Cafes'	SU_P4	WC	SA_S4	Student affairs	SA_A3	Computer Labs	SA_E4
		Public gathering zones	SU_P5	Student breaks Rooms	SA_S5			Laboratories	SA_E5
								Research Labs	SA_E6
		Streets	SU_P6	Stores	SA_S6			Workshops	SA_E7
		Pedestrian paths	SU_P7	Services Rooms	SA_S7			Flexible cave screen	SA_E8
		Parking spaces	SU_P8					Meeting rooms and seminars	SA_E9
								Design and Art Studios	SA_E10
								Multi-use areas	SA_E11
								Library	SA_E12

The activities conducted in universities whether educational, administrative, social and entertainment are articulated in Table (4).

Table (4) Activities conducted in universities							
Entertainment Activities		**Social and Life Activities**		**Administrative Activities**		**Educational Activities**	
Shopping	(AR1)	Volunteering	(AS1)	Registration	(AA1)	Active Learning	(AE1)
Sport	(AR2)	Religious activities	(AS2)	Budgets and accounting	(AA2)	Blended Learning	(AE2)
hobbies	(AR3)	Life activities	(AS3)	Inter-institution coordination	(AA3)	Collaborative Learning	(AE3)
Fairs	(AR4)	Healthcare	(AS4)	Record keeping supervision	(AA4)	Independent Learning	(AE4)
Theater	(AR5)	Contact	(AS5)	Service management	(AA5)	Project-Based Learning	(AE5)
Parties	(AR6)	Moving	(AS6)	Meetings	(AA6)	Game-Based Learning	(AE6)
						Problem-Based Learning	(AE7)

When introducing 4IR concepts to existing universities, some people, activities and spaces will be affected. Activities shape the students' development as well as other target groups in universities, as people-environment relationships are intertwined and impact human behavior. So, activities performed within university spaces should be identify people performing such activities and to develop a mapping to the 4IR concepts related to them as shown in Table (5) based on findings extracted from literature. The following Table (5) shows the identification of 4IR concepts impact on university components (activities, spaces, and people).

C1	Cyber-Physical System (CPS)	C9	Robots
C2	Machine Learning	C10	3D Printing
C3	Cloud Computing	C11	3D Scanning
C4	Internet of Things (IoT)	C12	Mobile Computing
C5	Big Data	C13	Biosensor
C6	Augmented Reality (AR)	C14	Biometrics
C7	Virtual Reality (VR)	C15	Digital Fabrication
C8	Holography	C16	Computer Vision

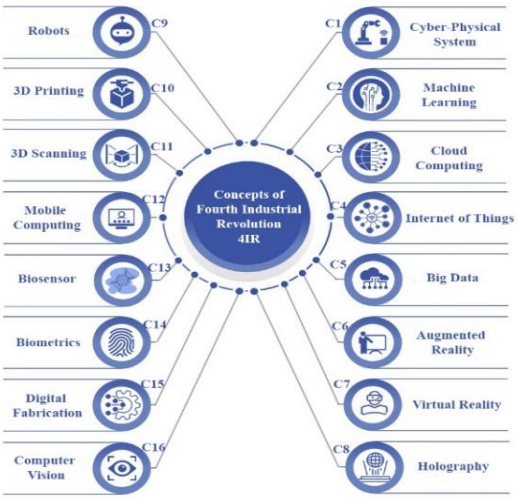

Fig (3) An extracted set of concepts of the 4IR that has direct impact on transforming existing universities to the 4G universities

4.2. Analysis of the expected impact of 4IR technologies and educational spaces "urban and architectural" in 4G Universities.

Universities are mainly materialized in urban spaces and buildings. To assist in accomplishing one of the main functions of universities "which is education", then the design of educational spaces that aid students in learning, innovation, and success should be carefully addressed. There are some basic principles for the design of educational spaces within universities to help achieve their aims. These principles include making learning spaces flexible, aiding students in cooperative learning, providing the best technological solutions, helping students to relax and concentrate, and connecting indoor spaces to outdoor ones. The emergence of the 4IR concepts impacted educational spaces within universities: in a direct, strong manner; or in an indirect manner. Table (6) shows the expected impacts of 4IR concepts on educational spaces in universities to be transformed to 4G universities.

Table (5) Mapping of 4IR concepts and its relation to people, activities and spaces in universities *(Ferriman, 2020; Hafezi et.al, 2018; Gueye & Exposito ,2020)*

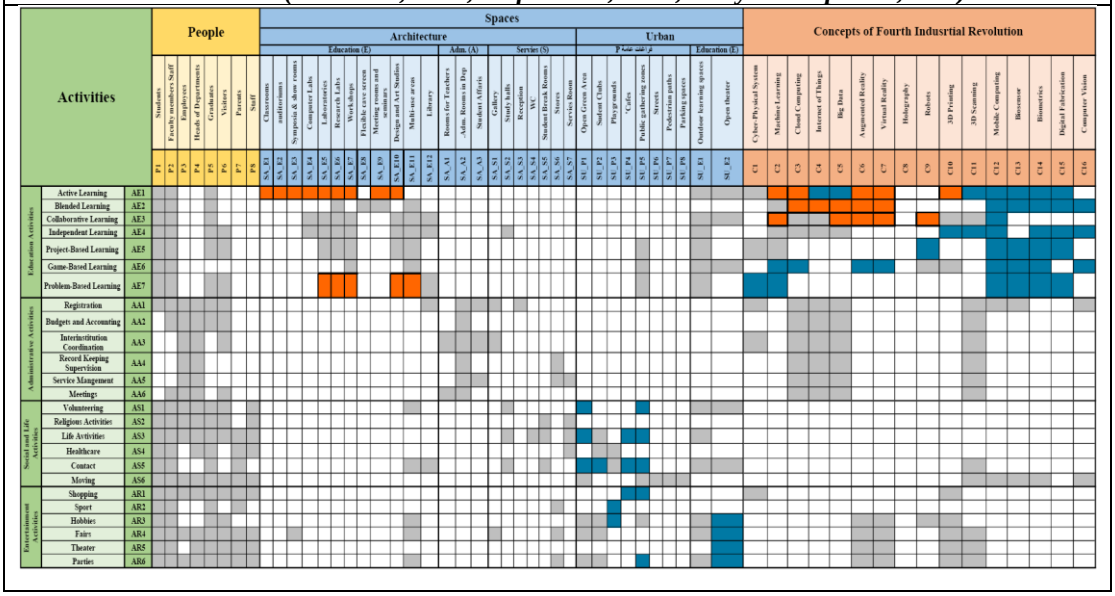

Table (6) The expected impacts of 4IR concepts on educational spaces in universities to be transformed to 4G universities

Concepts of Fourth Generation Industrial (C)		Spaces (S)														
		Built Spaces (A)													Urban Spaces(U)	
		Education (E)														
		Classrooms	auditoriums	Symposia & show rooms	Computer Labs	Laboratories	Research Labs	Workshops	Flexible cave screen	Meeting rooms and seminars	Design and Art Studios	Multi-use areas	Library		Outdoor learning spaces	Open theater
		SA_E1	SA_E2	SA_E3	SA_E4	SA_E5	SA_E6	SA_E7	SA_E8	SA_E9	SA_E10	SA_E11	SA_E12		SU_E1	SU_E2
Cyber-Physical System	C1	1	1	2	3	2	3	1	3	2	1	1	3		2	1
Machine Learning	C2	1	1	1	3	3	3	3	1	1	3	3	3		1	1
Cloud Computing	C3	2	2	1	2	2	2	2	2	1	2	2	1		1	1
Internet of Things	C4	1	1	2	2	1	2	2	2	1	1	1	3		1	1
Big Data	C5	1	1	2	2	1	1	1	1	2	1	1	2		1	1
Augmented Reality	C6	1	1	1	3	3	3	3	3	1	1	1	1		2	2
Virtual Reality	C7	1	1	1	3	3	3	3	3	1	1	1	1		2	2
Holography	C8	1	1	1	1	3	3	3	3	1	1	3	1		1	1
Robots	C9	3	3	3	3	3	3	3	3	3	3	3	3		1	1
3D Printing	C10	1	1	1	3	3	3	3	1	1	2	2	1		1	1
3D Scanning	C11	1	1	3	3	3	3	3	1	1	2	2	1		1	1
Mobile Computing	C12	3	3	3	3	3	3	3	3	3	3	3	3		3	3
Biosensor	C13	1	1	1	1	3	3	3	1	1	1	3	1		3	2
Biometrics	C14	3	3	3	3	3	3	3	3	3	3	3	2		3	2
Digital Fabrication	C15	1	1	2	1	3	3	3	2	1	2	1	1		1	1
Computer Vision	C16	1	1	1	1	1	1	1	1	1	1	1	1		3	2

Expected Impact	
3	Strong
2	Medium
1	Weak

The expected impacts of the 4IR concepts are extracted from Table (6) as follows:

- The expected impact **Mobile Computing (C12)** is strong on all indoor and outdoor educational spaces.
- The expected impact of **Robots (C9)** is strong on all indoor educational spaces.
- The expected impacts of **Biometrics (C14)** are strong on all indoor educational spaces, and medium for the library. It has also a strong impact on outdoor learning spaces, and a medium one on the open theater in outdoor learning spaces.
- The expected impacts of **Augmented & Virtual Reality (C6 & C7)** are strong on the following indoor educational spaces: (computer labs, labs, research labs, workshops, flexible cave screen); and medium on outdoor educational spaces.
- The expected impact of **Machine Learning (C2)** is strong on the following indoor educational spaces: (computer labs, labs, research labs, workshops, design and art studios, multiple-use spaces, the library).
- The expected impact **of Holography (C8)** is strong on the following indoor educational spaces: (computer labs, labs, research labs, workshops, flexible cave screen, multiple-use spaces).
- The expected impacts of **3D Printing (C10)** are strong on the following indoor educational spaces: (computer labs, labs, research labs, workshops); and medium on the following indoor educational spaces (design and art studios, multiple-use areas).
- The expected impacts of **3D Scanning (C11)** are strong on the following indoor educational spaces: (computer labs, labs, research labs, workshops, symposia and show rooms); and medium on the following indoor educational spaces (design and art studios, multiple-use areas).
- The expected impacts of **Cyber-Physical System (C1)** are strong on the following indoor educational spaces: (computer labs, labs, research labs, flexible cave screen, the library); and medium on the following indoor educational spaces (symposia and show rooms, labs, seminars and meeting rooms), as well as outdoor learning spaces in outdoor educational areas.

- The expected impact of **Cloud Computing (C3)** is medium on the following indoor educational spaces: (computer labs, labs, research labs, workshops, design and art studios, flexible cave screen, multiple-use areas).
- The expected impact **of Internet of Things (C4)** is strong on the library in indoor educational spaces, and medium on (classrooms, auditoriums, computer labs, labs, research labs, workshops, flexible cave screen) in indoor educational spaces.
- The expected impact of **Big Data (C5)** is medium on the following educational spaces: (symposia and show rooms, computer labs, seminars and meeting rooms, the library).
- The expected impact**s of Biosensors (C13)** are strong on the following indoor educational spaces: (labs, research labs, workshops, multiple-use areas), as well as outdoor educational spaces such as the outdoor learning areas; and medium impact on the open theater in outdoor learning areas.
- The expected impacts of **Digital Fabrication (C15)** are strong on the following indoor educational spaces: (labs, research labs, workshops); and medium on (symposia and show rooms, labs, flexible cave screen, design and art studios).
- The expected impacts of **Computer vision (C16)** are strong on outdoor educational spaces, such as the outdoor learning spaces, and medium on the open theater.

4.3. Digital Transformation and E-Learning concepts

Various concepts have recently emerged such as digital transformation which is extremely important for the competition universities to stay in global. Digital transformation may be defined as enhancing operations of institutions (universities) to meet people's requirements efficiently through the best utilization of data and technology *(Takyar, 2020)*. The rate of change is rapidly increasing in universities and higher education; a change that will continue in the coming years, as "digital transformation" started to play an important role in universities. Thus, universities must prepare their students for the digital age; not just through introducing technical knowledge with it relevant challenges and opportunities, but also by preparing students to be digitally qualified for new emerging jobs. This requires universities to reshape the different learning approaches to adapt to digital transformation in education as shown in Fig (4) presenting elements affecting digital transformation in education. Learning environments must also be redesigned to correspond to the digital transformation, whether in space requirements for technologies, use, or function.

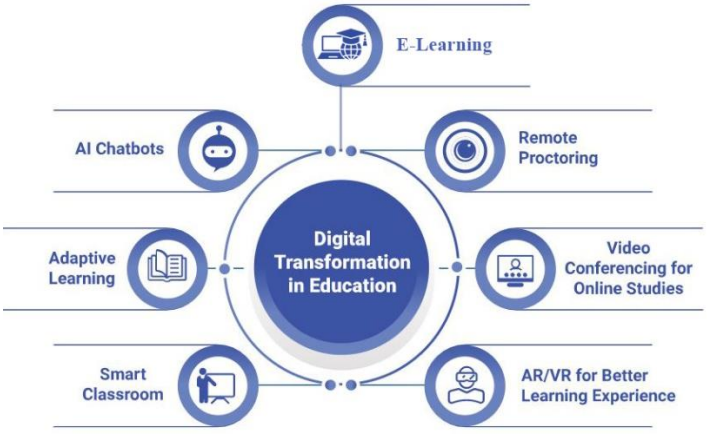

Fig (4) Dimensions of Digital Transformation in Education

One of the main dimensions of digital transformation in education is e-learning which includes the following issues:

- The educational process through which information is presented to students using computers, software, and synchronous /non-synchronous interactive internet tools, whether in closed intranets within the university, a network shared by universities, or over the internet. *(Al-Ghadyan, 2010)*
- Using computer and internet technologies to present a huge number of solutions to enable education and improve performance. It is a technological approach used in teaching and learning, as the computer and the internet are now necessary to enable knowledge and skills transfer. *(Raheem & Khan, 2020)*

Method that use computer technologies with different software applications, in addition to online services basically to enhance traditional learning and provide additional activities to students. *(Ozadowicz, 2020)*

Some of the various methods used for e-learning in universities are shown in Table (7).

Table (7) Methods used for e-learning in universities

Methods		References
1	Computer-Based Learning	*(Raheem&Khan,2020; Li&Lalani,2020; Amir et.al., 2020; Ozadowicz,2020; Chaka,2020; Mahaye,2020)*
2	Web-Based learning	
3	Problem or Question-Based Learning	
4	Project-Based Learning	
5	Virtual Education	
6	Digital Collaboration	
7	Video Conference	
8	Digital Libraries	
9	Blended Learning	
10	Peer Learning	

4.4. Impact of COVID-19 Pandemic on some 4IR technologies inside educational spaces in universities

The emergence of COVID-19 led to accelerating the emergence of many 4IR concepts and adopting various digital technologies in the education sector. Before the pandemic, digital transformation of educational services in universities occurred at a slow pace; with various higher education institutions not adopting such modern systems/technologies. Yet, the emergence of COVID-19 led to increasing the adoption of some 4IR concepts. The use of virtual learning environments over the internet is increased, as well as students' participation by non-synchronous messages, discussion boards, or synchronous classrooms via video conferences. The adoption of 4IR concepts for digital transformation in learning within universities started at different levels as follows:

- <u>The campus:</u> Thermal check upon entrance, non-touching attendance, social distancing alarm systems, and face-mask discovering systems.
- <u>Learning methods:</u> Video conferences, using AR/VR in learning, adaptive education, learning platforms, and using AI and Chatbots to answer queries introduced by students.
- <u>Teaching methods:</u> Smart classrooms, evaluation over the internet, AI usage to monitor, process, and analyze data.

Although crises tend to reshape societies, it is still uncertain about how the COVID-19 pandemic will permanently impact practices and the learning environments within universities. Based on what happened in 2020 and 2021 till now, and the introduction of 4IR concepts in education and learning environments within universities; the expected impacts of COVID-19 Pandemic on accelerating the emergence of some 4IR concepts in educational spaces in universities are forecasted as shown in Table (8).

Table (8) The expected impacts of COVID-19 Pandemic on some 4IR concepts in educational spaces in universities

Concepts of Fourth Generation Industrial (C)		Concepts that effected after COVID-19	Spaces: Built-Spaces: Education: Classrooms auditoriums	Symposia & show rooms	Computer Labs	Laboratories	Research Labs	Workshops	Flexible cave screen	Meeting rooms and seminars	Design and Art Studios	Multi-use areas	Library	Urban Spaces: Outdoor learning spaces	Open theater
			SA_E1	SA_E2	SA_E3	SA_E4	SA_E5	SA_E6	SA_E7	SA_E8	SA_E9	SA_E10	SA_E11	SA_E12	SU_E1	SU_E2
Cyber-Physical System	C1		1	1	2	3	2	3	1	3	2	1	1	3	2	1
Machine Learning	C2		1	1	1	3	3	3	3	1	1	3	3	3	1	1
			3	3	3	3	3	3	3	3	3	3	3	3	2	2
Cloud Computing	C3		2	2	1	2	2	2	2	2	1	2	2	1	1	1
Internet of Things	C4		1	1	2	2	1	2	2	2	1	1	1	3	1	1
Big Data	C5		1	1	2	2	1	1	1	1	2	1	1	2	1	1
			3	3	3	3	2	2	2	2	3	2	2	3	1	1
Augmented Reality	C6		1	1	1	3	3	3	3	1	1	1	1	2	2	
			2	2	2	3	3	3	3	2	3	2	2	2	2	
Virtual Reality	C7		1	1	1	3	3	3	3	1	1	1	1	2	2	
			2	2	2	3	3	3	3	2	3	2	2	2	2	
Holography	C8		1	1	1	1	3	3	3	3	1	1	3	1	1	1
Robots	C9		3	3	3	3	3	3	3	3	3	3	3	3	1	1
			3	3	3	3	3	3	3	3	3	3	3	3	2	2
3D Printing	C10		1	1	1	3	3	3	3	1	1	2	2	1	1	1
			1	1	1	3	3	3	3	1	1	3	3	1	1	
3D Scanning	C11		1	1	3	3	3	3	3	1	1	2	2	1	1	1
Mobile Computing	C12		3	3	3	3	3	3	3	3	3	3	3	3	3	3
			3	3	3	3	3	3	3	3	3	3	3	3	3	3
Biosensor	C13		1	1	1	1	3	3	3	1	1	1	3	1	3	2
Biometrics	C14		3	3	3	3	3	3	3	3	3	3	3	2	3	2
			3	3	3	3	3	3	3	3	3	3	3	3	3	3
Digital Fabrication	C15		1	1	2	1	3	3	3	2	1	2	1	1	1	1
Computer Vision	C16		1	1	1	1	1	1	1	1	1	1	1	1	3	2
			1	1	1	1	1	1	1	1	1	1	1	1	3	2

Expected Effect before Covid-19		Expected Effect after Covid-19	
		3	Strong
2	Medium	2	Medium
1	Weak	1	Weak

It is worth noting that there are some of the 4IR concepts whose expected impacts on learning within universities cannot be forecasted as follows:

- (C1) Cyber-Physical System
- (C3) Cloud Computing
- (C4) Internet of Things
- (C8) Holography
- (C11) 3D Scanning
- (C13) Biosensor
- (C15) Digital Fabrication

Meanwhile, other 4IR concepts are observed to have been accelerated and increased with a corresponding impact on learning and learning environments within universities as follows: *(Takyar, 2020; Kang, 2021; Mhlanga & Moloi, 2020; Lee & Han, 2021; Lewis, 2021)*

- **Machine Learning (C2):** strong, after it was weak on the following indoor educational spaces: (classrooms, auditoriums, symposia and show rooms, flexible cave screen, seminars and meeting rooms), and medium – after it was weak – on outdoor educational spaces.
- **Mobile Computing (C12):** strong on all indoor and outdoor educational spaces.
- **Robots (C9):** strong on all indoor educational spaces.

- **Biometrics (C14):** strong on all indoor educational spaces, but medium for the library. It has also a strong impact on outdoor learning spaces, and a medium one on the open theater in outdoor learning spaces.
- **Augmented & Virtual Reality (C6 & C7):** strong on the following indoor educational spaces: (computer labs, labs, research labs, workshops, flexible cave screen), and medium on outdoor educational spaces.
- **Machine Learning (C2):** strong on the following indoor educational spaces: (computer labs, labs, research labs, workshops, design and art studios, multiple-use spaces, the library).
- **Big Data (C5):** strong after it was weak in the following indoor educational spaces: (classrooms and auditoriums), and strong – after it was medium- on the following educational spaces: (symposia and show rooms, computer labs, seminars and meeting rooms, the library), and medium – after it was weak – in labs, research labs, workshops, flexible cave screen, design and art studios, multiple-use areas.
- **3D Printing (C10):** strong on the following indoor educational spaces: (computer labs, labs, research labs, workshops), and medium on the following indoor educational spaces (design and art studios, multiple-use areas).
- **Augmented & Virtual Reality (C6 & C7):** strong – after it was weak – in design and art studios, and medium – after it was weak – in (classrooms, auditoriums, symposia and show rooms, seminars and meeting rooms, multiple-use areas, the library) in indoor educational spaces.
- **Biometrics (C14):** strong – after it was medium – in the library in indoor educational spaces and the open theater in outdoor learning spaces.

It is also observed *(Takyar, 2020; Kang, 2021; Lee & Han, 2021; Walley et.al., 2021)* that the expected impact of **Mobile Computing (C12) & Computer Vision (C 16)** remains strong, even after the emergence of COVID-19 Pandemic, in educational spaces.

5. Discussion

The transformation of universities into 4G universities requires effective utilization and application of the 4IR concepts in the educational spaces within universities. This was taking place before the COVID-19 Pandemic, but at a slow pace. Due to the emergence of COVID-19, the adoption of such concepts in educational spaces within universities started to accelerate.

It is observed based on the analysis of related literature that some 4IR concepts have a strong impact in all indoor/outdoor educational spaces, e.g. Mobile Computing. This will affect in changing the design of educational spaces because it helps students to access information and services anywhere or while moving. Face-to-face attendance is not as essentials it was used to be since students can attend lectures from anywhere, as shown in Fig (5).

Fig (5) Example of adopting the 4IR concept of Mobile computing in various settings as an educational space

In addition, the 4IR concept of VR/AR aids students to conduct experiments with access capabilities that were not earlier available. It enables them to attend workshops or

virtual lab tests in other universities, just by providing the required technologies in educational spaces as shown in Fig (6).

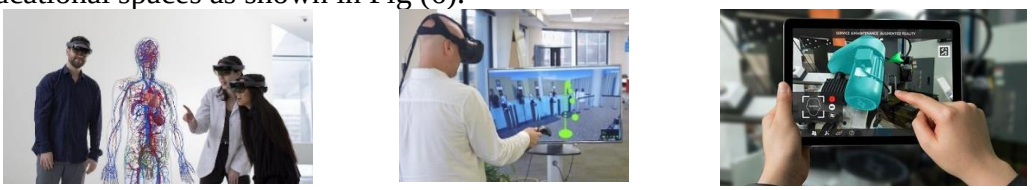

Fig (6) Examples of the Adoption of AR/VR concepts in educational spaces

Meanwhile, there are other concepts which are expected to have a strong impact on universities after the COVID-19, such as the Biometrics, due to the increasing usage of its application to aid in reducing the outbreak of COVID-19. Its applications include thermal check, social distancing alarm, wearing masks, non-touching attendance, etc. The use of Digital Fabrication helps to increase innovation and creativity of students by conducting experiments and workshops which were previously taken in the form of theoretical knowledge of technologies, without being directly exposed to physical manifestations. This requires designing spaces with new technologies, and specific requirements. Furthermore, some 4IR concepts –such as Big Data, IoT, and Cloud Computing – have helped students, during the COVID-19 Pandemic, to complete their administrative and service procedures (registration, paying fees, etc.) without the need of face-to-face transactions. All these will impact the design of educational spaces, if not all spaces within universities; administrative, service, and public spaces. The successful transformation to 4G universities, requires the adoption of the 4IR concepts into various spaces within universities. In addition, the COVID-19 Pandemic has impacted the acceleration level of adopting some of the 4IR concepts, whereas the full impact has not yet been fully realized.

6. Conclusion

The world went through a series of industrial revolutions, starting from the First Industrial Revolution to The Fourth Industrial Revolution (4IR), which is characterized by speed and technologies and has various concepts that need to be applied in universities to keep pace with such development and produce graduates keeping such pace in future labor markets. The 4IR concepts must be carefully addressed and wisely introduced and applied to such universities. When such concepts are applied to educational spaces in existing universities, then the 4IR concepts are expected to have a strong impact on transforming existing universities to 4G universities. The emergence of the COVID-19 Pandemic has affected the acceleration level of adopting some of these 4IR concepts. Further studies are required to comprehensively assess the roles and limitations of these 4IR concepts in the successful transformation to 4G universities.

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