Chapter

Digital Transformation: The Age of Innovations in Business and Society

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Abstract

This chapter considers main factors of digital transformation in business and society. The latest studies of digital ad spend in Europe and a number of marketing technology solutions all over the world within the period 2011–2020 have confirmed a rapid development of digital technologies in business and society. It was justified that due to digitalization process companies have to revise their priorities and modify their main strategic goals for simultaneous achievement of commercial efficiency and a social effect. These goals need some adjustment to specific requirements and wishes of main process participants that form five levels of approval. Proposed marketing management model in digital transformation of business and society contains basic components, which lie in the digital contour. Responses of millennials (the people born at the turn of the century) on the use of digital technologies in different spheres of life are analyzed. The pilot research allowed to distinguish three groups of millennials depending on how actively they use digital technologies in different spheres of life. Main directions of innovative marketing management development are defined. The opportunities of implementing functionality of artificial intelligence, neuromarketing, augmented and virtual reality, marketing technologies MarTech in company business-processes are studied.

Keywords: digital transformation, marketing management, a millennial, a business-process, a society, a digital technology, neuromarketing, MarTech, augmented and virtual reality, artificial intelligence

1. Introduction

Nowadays technologies and innovations actively have effect on all spheres of human life triggering digital transformation in business and society. For the last two decades, digital technologies have rapidly developed and scaled. Wide spread of the Internet, the availability of various types of devices, the development of digital platforms, launching of social media and applications caused the emergence of generation of millennials, that is, those who were born at the turn of the century and have been growing within this period. These young people do not almost represent their lives without digital technologies, actively use them in their everyday lives and are mastering new functionalities and adjusting to new realities of a society. Unlike the senior generation, the youth aged from 18 to 25 can freely orient in the digital space and have a little different rational, emotional and behavioral responses when interacting with a society and environment. Millennials have become the main driving force of digital transformation in business and society due to their skills of mixing online and offline communication, rapid gaining digital skills, dexterity of working with databases and a desire to integrate technologies, products and systems in all spheres of life.

This young generation represents new requirements for goods, services or ideas and wishes more and more innovative products. By monitoring and analyzing customer needs and expectations, global technological corporations significantly contribute to the research and development of new products and digital solutions, which are gradually filling all spheres of life. Adjustment to society digital transformation factors and replacement of existing business models by more innovative ones have a significant impact on the development of digital skills of the senior generation and stimulate their use at work and everyday life for communication or doing certain actions.

Results of studying the status of digital marketing technologies in the world within the last 10 years witness that a number of only marketing technology solutions are growing in average at 995 items per year and at the end of 2020, there were 8000 items. However, for the development of successful business in digital transformation of society, it is not enough whether a company has only innovative technologies and products. A company has to focus on real human values and better understand its customers, employees, business partners, etc. In this connection, managerial staff has to modify traditional approaches to company management taking into account new trends and find innovative solutions to improve lives of people and society as a whole. An innovative approach to company administration in the new realities is implementation of a complex marketing management system containing a dual strategic goal—simultaneous achievement of maximum economic efficiency and a social effect.

Marketing management development depends on available digital technologies affecting people's lifestyle and transforms a whole society. Among innovative technologies used in the administration of company business processes by managerial staff, it is possible to distinguish the most experimental ones, such as artificial intelligence, neuromarketing, augmented or virtual reality and marketing technology MarTech. These four technologies grounding on the knowledge of different sciences combine variable methods and tools and actively develop integrating one to another and acquiring new functionality.

The problem to be solved in this chapter is to define factors of digital transformation impact on business and society to modify the existing approaches in management in accordance with the modern trends. To solve this comprehensive problem, the research was carried out in five stages: At the first stage, the main factors of digital transformation in business and society were defined; at the second stage, the basic hypotheses of marketing management in modern conditions were formulated; at the third stage, the up-to-date marketing management model in digital transformation of business and society was developed; at the fourth stage, the use of digital technologies by millennials in their everyday lives was studied; and at the fifth stage, the main directions of marketing management innovation development were defined.

2. Digital transformation: an age of innovations in business and society

2.1 Main factors of digital transformation in business and society

The COVID-19 pandemic has become a real challenge for business and society all over the world. The development trends of the period 2019–2021 have demonstrated that for survival at the market and for successful realization of its activity, the company needs the following: flexibility of managerial staff's thinking, adaptation to digital transformation of society and replacement of the existing business models by more innovative.

Since the beginning of pandemic technologies have developed rapidly and for many countries (especially for the countries of Europe and Northern America) have become the main way of connection between people (Human-to-Human, H2H), business partners (Business-to-Business, B2B), companies and consumers (Business-to-Consumer, B2C). Let us analyze the main factors of digital transformation in business and society, which are structured on **Figure 1**.

The up-to-date realities of society digitalization have determined the spiral development of companies as a result of effects of the following external factors: customer requirements and needs in communication and innovative products; business interests of global technological corporations; significant investments in scientific research and development and creation of innovative technologies and products.

Customer needs and requirements in communication and innovative products trigger the spiral of society digital transformation development. However, the locomotive of the up-to-date stage of development is global technological corporations in big batches producing personal computers, laptops, netbooks, tablets, smartphones and other devices having features to connect to global networks and systems. Marketing tools of global technological corporations are aimed, on the one side, to popularize new innovative products and involve partners in rising functionality of equipment and devices, and, on the other side, to increase a number of potential and existing customers and provide maximum product sales volumes.

The main factors of digital transformation in business and society are as follows: competition at the market and mixing of online and offline formats, up-to-date digital skills of humans, the availability of huge databases containing data on different

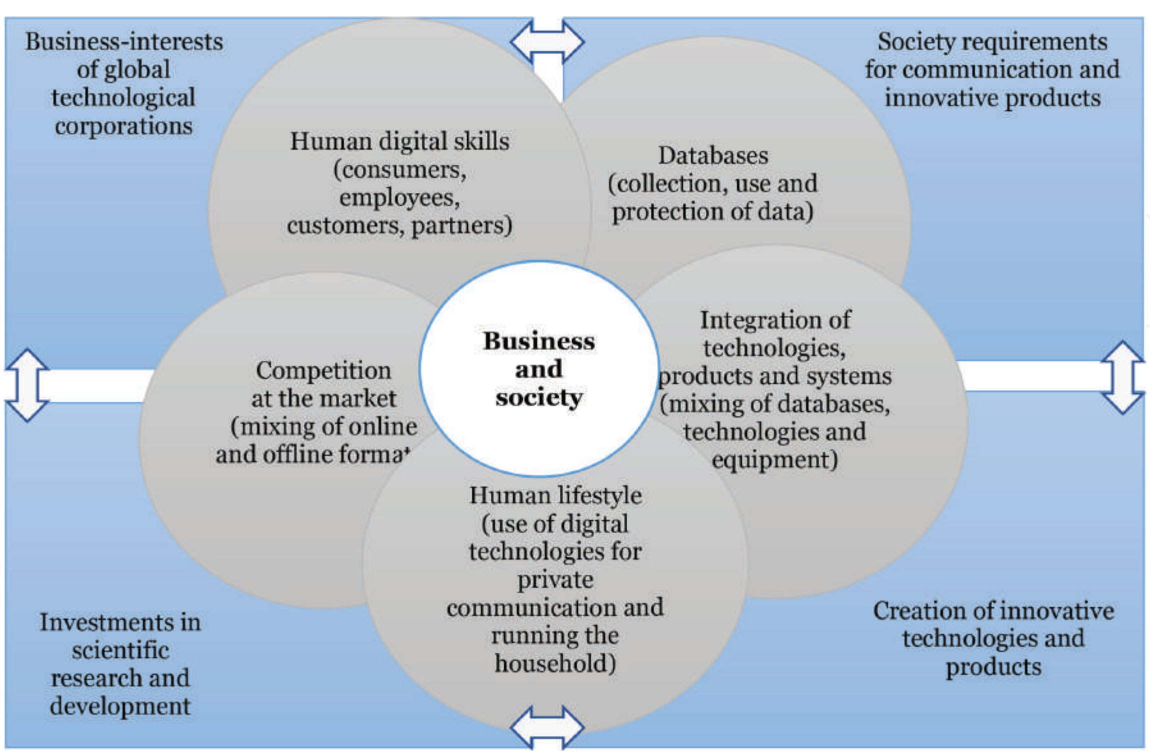

Figure 1.
Main factors of digital transformation in business and society.

aspects of society and business development, the use of digital technologies by people in various life spheres, integration processes of mixing technologies and devices, access to databases.

Competition at the market stimulates companies to active development of their online business [1]. At the same time, traditional offline business is transformed remaining the basis of digital superstructure. The companies, which have been working at the market for a long period, are afraid to lose their positions under the pressure of new ambitious players. Analyzing significant benefits from the use of digital technologies and products, these companies suppose that investment into this field is a precondition of their success and an opportunity of strengthening their own positions at the market [2–4]. It was what determined the popularity of creating new technological platforms, especially those providing automation of company's business processes, the efficient use of databases for making optimal management decisions, monitoring needs of individual consumers and a whole society.

Accumulation of vast data scopes by companies has determined the necessity of developed technologies for collecting, using and protection of information. Big Data help managerial staff to make balanced administrative decisions and develop effective innovative strategies mixing business interests, needs and wishes of a society. Besides, operational decisions of company employees often require approval at different levels that increase time for their acceptance and implementation. Integration of digital technologies, devices and systems of a company allows its employees to get the needed information quickly, increase overall performance and response to changes fast.

Digital technologies in business and society are actively developing (**Figure 2**). For example, total digital ad spend in Europe for the last 10 years (2011–2020) has been rising in average over €5 billion annually. The data have been received grounding on the analysis of 28 European countries: Austria, Belarus, Belgium, Bulgaria, Czech Republic, Croatia, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Norway, Poland, Russia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, UK and Ukraine [5]. At these growing rates in 2022, digital ad spend will exceed €79 billion. The results of studying development of digital marketing technologies all over the world within the analogous period witnessed that a number of marketing technological solutions have been rising in average over 995 items each year [6]. At these growing rates in 2022, a number of MarTech solutions will exceed 9900 items.

However, for structuring successful business under the conditions of digital transformation of society it is not enough if a company only has innovative technologies and products. A company has to understand its customers, employees, business partners better to know what is important for them, helping to create new products, services, tools and solutions, which will really improve the life of people and a whole society. A company has to focus on real human values and provide that its promises were matched with its competences and capabilities. Therefore, managerial staff must modify the available approaches to administration taking into account society digitalization trends.

2.2 Marketing management as an innovative approach to company administration

Marketing management is an innovative approach to company administration in conditions of changeable environment for achieving key objectives. At the same time,

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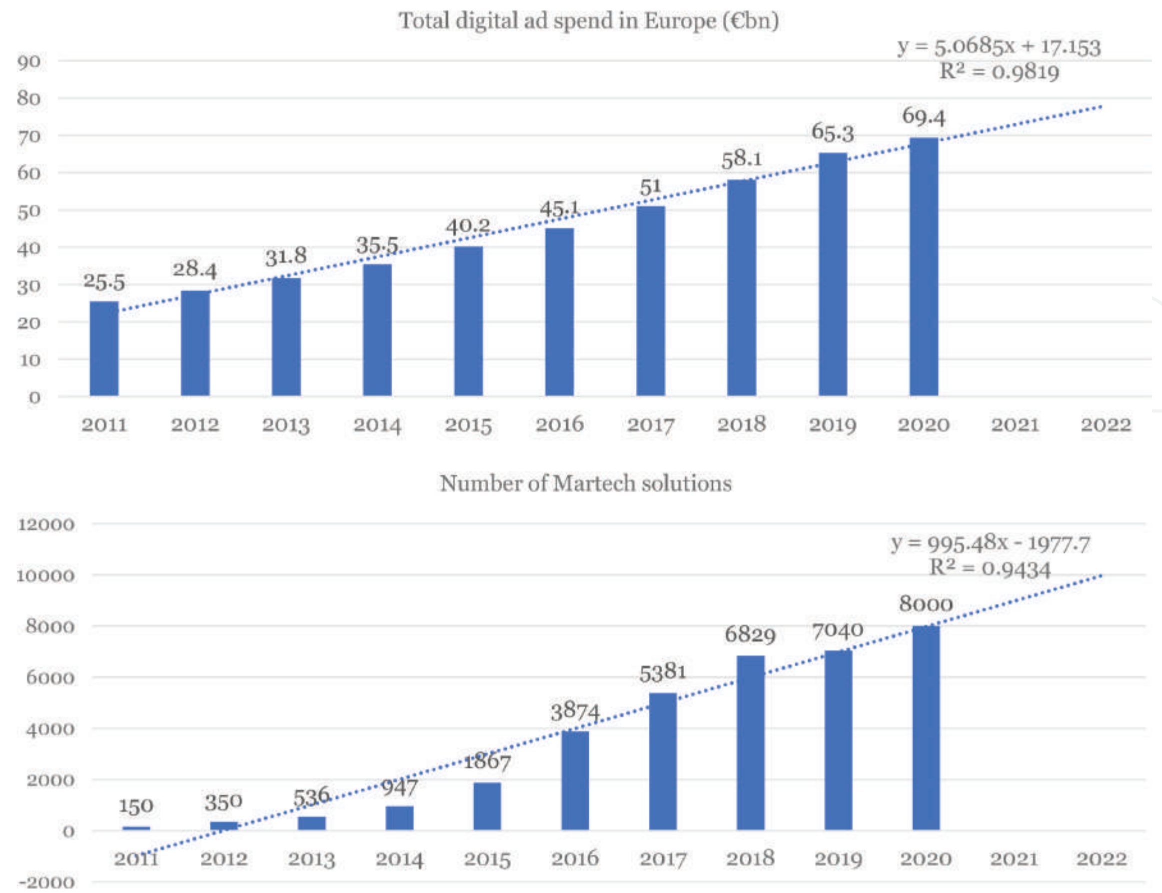

Figure 2.
Development of digital technologies in business and society [5, 6].

key objectives have to be harmonized with strategic goals and ethical codes acceptable in a society and must help to receive maximum economic and social effects.

Basic hypotheses of marketing management are as follows:

- A company functions within the environment having limited resources that stimulates its permanent struggle for survival. (According to survival theory, a company continuously adjusts and changes its fighting methods, but the essence is left unchangeable [7]).
- Marketing management contains a large number of elements bounded to each other and creating a definite integrity. (According to system theory, it characterizes patterns of creation, functioning and development [8]).
- A company functions within a society where people try to get a definite benefit from their lives. (According to Adam Smith's theory, private interests of people stimulate the level of their performance and individual development and also define the overall well-being [9]).
- Marketing management contains a complex of dynamic objectives, and to achieve strategic goals, optimal distribution of resources by each of them is required. (According to Pareto optimality theory, this is the achievement of such a condition when it is impossible to improve one business process without worsening of another one [10]).

- Marketing management best achieves established goals by arrangement of free and competitive exchange between all participants based on individual freedom principle. (According to individual choice theory, people are responsible for their own actions and are able to find the best way of interaction that can be reached if there are benefits for both parties [11]).

- Strategic decisions in marketing management are made by subjects entrusted with governing authorities after a collective discussion. (According to Arrow's impossibility theorem, it is impossible to participate in making a collective decision based on the common priorities without taking into account individual priorities [12]).

Consequently, the mathematical function of possibility to implement marketing management within a company is complex, dynamic, pluralistic and tolerant to the diversity of economic and social regulations.

Any business activity is realized to achieve a result. In marketing management, the main results are the achievement of commercial effectiveness and receiving a social effect. Implementation of the first goal allows a company to maintain balanced development, to provide an optimal level of profitability and income from its business activity, and to increase the volumes of selling goods, services or ideas at a definite level. At the same time, implementation of the second goal helps a company to achieve a certain social effect, namely to create a definite need or destroy it, to teach customers how to use products in all possible cases and in optimal volumes, to assign a definite status or fashion to products [13]. The mentioned company marketing management goals need a significant adjustment to specific requirements of main process participants that form five levels of approval (**Table 1**).

Therefore, major company marketing management goals have a certain hierarchy and structure. Economic goals more refer to company's commodity, distribution and price policies. Social goals are focused on achieving a definite effect by psychological impact of marketing events on consumer mentality and behavior, a general impression from a product. When implementing marketing management within a company, all goals approved at the mentioned five levels shall be optimally bounded to each other.

2.3 Up-to-date marketing management model in digital transformation of business and society

Digital transformation had an impact on companies' business processes. Transparent, clear and consequent communication allowed flexible interacting with a wide circle of customers and partners attracting the new and maintaining the current ones. To a certain extent, the modern marketing cannot exist without innovative technologies and products. This area is actively developing, and by now, there have been hundreds of digital tools for reducing the risks of making inefficient managerial decisions and increasing performance of employees. Technologies are becoming a much more significant component of marketing management, and there appear new digital tools to control the task fulfillment, employee motivation, arrangement and coordination of business processes. Correspondingly, managerial staff have to create such a marketing management model in digital transformation, which will become a competitive advantage of a company and enable to respond the market needs rapidly and flexibly. Nowadays, it is not enough to choose any innovative tool and test it. It is necessary to comprehensively implement a carefully chosen technology into a

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Levels of approval		Major company marketing management goals	
		Commercial effectiveness	**Social effect**
1	Goals of company owners or managerial staff	• Profitability • Efficiency • Increase of a market share • Financial stability • Economic activity development	• Formation of consumer priorities • Positioning at the market • Awareness of goods, services and ideas • A product or a company status
2	Partner goals	• Maintenance of commercial effectiveness • Achievement of joint commercial goals • Mutual support • Joint project financing	• Creation or support of a definite need or a social effect • Maintenance of a product awareness • Conducting joint social events
3	Consumer goals	• Product quality and design • Less expenses on buying and servicing • Optimal balance "price/quality" • Comfort of buying and using	• Product manufacturing or safe use • Prestige or fashion • Esthetics and environment friendliness
4	Employee goals	• Increase of the wages and salaries fund • Optimal loading • Bonuses for improved results • Carrier development	• Work satisfaction • Social protection • Personal development • Social integration
5	Society goals	• Increased number of jobs • Preventing receipt of super profits • Social project financing	• Formation of definite perception • Attitude to the political climate • Social recognition

Table 1.
Major company marketing management goals by levels of approval.

company's activity and integrate technologies, products and systems at all levels. The up-to-date marketing management model in digital transformation of business and society is schematically presented on **Figure 3**.

The first block "Mission, vision, strategy of a company" is a key component of justifying the marketing management model. The strategy has to cover all business processes of a company, to set up internal and external communication channels and help to receive maximum economic and social effects. Strategic level of marketing management characterizes the process of long-term planning (for 1 year or more) and is focused on the development of strategies or scenarios for provision of company competitiveness and performance in the future. Tactic level of marketing management defines the process of short-term planning (for the period from a month to 1 year). At this stage, a strategy is detailed in compliance with modern realities, the current marketing conditions and business processes are analyzed, the planned indicators are established to provide the certain level of income and the order of actions is regulated to achieve company's strategic goals. Operational level of marketing management is realized by making a plenty of administrative decisions in all business areas in the real time.

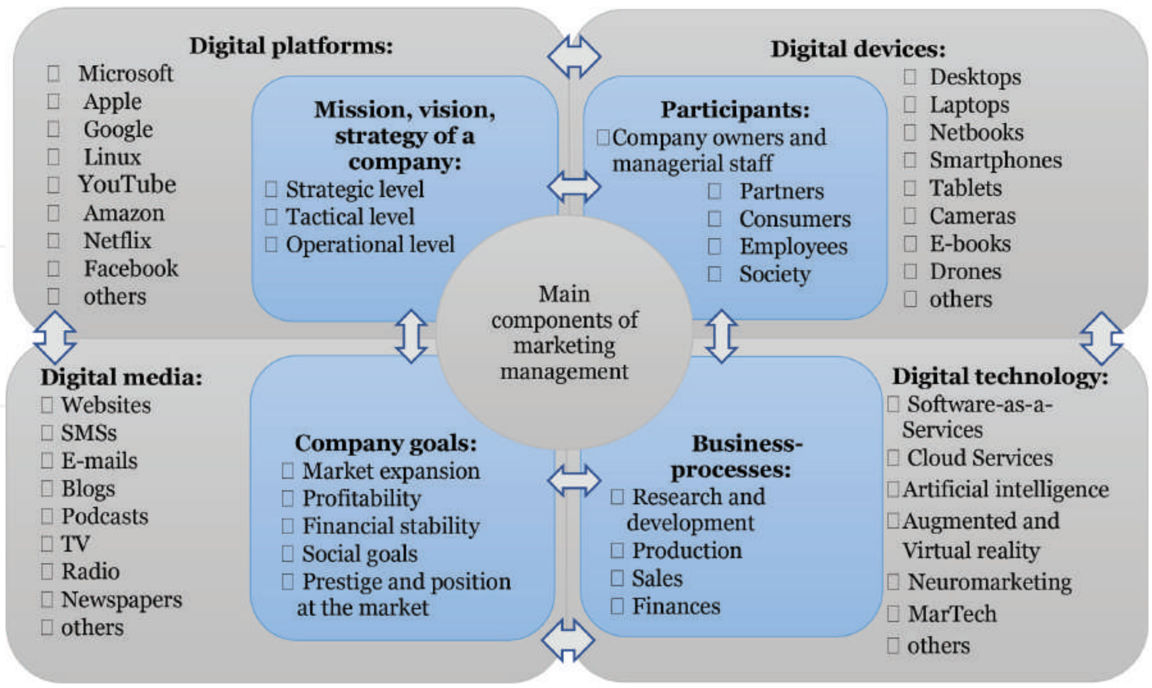

Figure 3.
The marketing management model in digital transformation of business and society.

The second block "Participants" covers the subjects of marketing management. For successful realization of a company's strategy, it is necessary to have a team of professionals who help to implement new digital tools into activities of all employees. Having received required skills, managerial staff and employees develop an innovative management system and stimulate digital communication with partners, customers and a society. This block is closely connected with the major marketing management goals at a company by levels of approval (**Table 1**). The first level is characterized by a dilemma of company owners and managerial staff regarding the effectiveness. At the next levels, marketing management goals are harmonized with partner agreements, customer requirements and wishes, company employee goals, society requirements and expectations [14–16]. Therefore, major marketing management goals have a definite hierarchy and structure.

The third block "Company goals" contains the following major marketing management goals: market expansion, profitability, financial stability, social goals, prestige and position at the market. They can be conditionally divided into two components—economic and social goals. Economic goals more refer to commodity, distributive and price policies of a company. The key market expansion indicators are a market share, a turnover, a role and significance of goods or services, new market volumes. To evaluate the profitability level, managerial staff analyzes profitability, reverse profitability, return on equity and return on total capital. To the key, financial stability indicators belong the following ones: creditworthiness, liquidity, self-financing structure, capital structure. Social goals are focused on gaining a certain effect through a psychological impact of marketing events on customer mentality and behavior, a general impression from a product. When defining a social effect, managers analyze employees' satisfaction with their work, wages, carrier development, social protection and social integration. At the same time, key indicators used to evaluate the prestige and position at the market are independence, image, political climate and social recognition. When marketing management is implemented within a company, all goals shall be optimally harmonized with each other.

The fourth block "Business-processes" contains the following main components: research and development, production, sales and finances. On the one hand, these are processes of planning, implementation, realization, correction and cancelation of fulfillment of managerial staff's decisions by company employees. On the other hand, these are the processes of interaction between technologies and systems, which provide digital optimization, operation of different devices, equipment operation speed, usability of interfaces, etc.

The mentioned four blocks of marketing management lie in the digital contour: digital devices ⇔ digital platforms ⇔ digital media ⇔ digital technologies. Nowadays, it is really difficult to separate decisions in business made by a human from technological solutions. Most decisions made by managerial staff are grounded on the analysis of databases and preventive digital models with the use of certain platforms and devices. Realization of business processes by company employees is impossible without digital media and technologies. The company's capability to propose a more personalized approach to each participant is a unique key to the use of innovative technologies and products. Accumulation of databases helps a company to better understand requirements and wishes of employees, partners, customers and a society in different regions. Quality analysis of available data performed by managerial staff allows to form a clearer mission, vision, strategy and goals. Effective realization of goals and tasks by employees creates more personalized suggestions of new technologies and products.

2.4 The use of digital technologies by millennials in their everyday lives

Unlike the senior consumers, millennials—the youth aged from 18 to 25 years old, who were born at the turn of the century (from 1997 up to 2003)—have different rational, emotional and behavioral responses to buying goods or services. Spread of the Internet, availability of devices, development of digital platforms, launching social media and applications were favorable for emergence of the audience with specific expectations for products according to their lifestyle. As a result of society digitalization, millennials are interested in the basic function of goods and services; however, they have specific emotional expectations for similar products.

To analyze emotional, rational and behavioral responses of the youth when buying goods or services, a pilot research was carried out among 350 respondents who gave answers to 100 questions divided into five blocks: (1) the use of digital technologies in everyday life; (2) areas of using augmented and virtual reality technologies; (3) buying goods and services online; (4) advantages and disadvantages of using devices, software and platforms and (5) responses to the use of digital technologies in everyday life. Summarized data on millennial responses to the use of digital technologies in different spheres of life are represented on **Figure 4**.

The answers of each respondent were summarized by each question and ranked in descending order. It enabled to distinguish three groups of millennials depending on a level of using digital technologies in different spheres of life: the first group (25%, 88 people)—the youth actively using digital technologies in all spheres of life; the second group (50%, 174 people)—the respondents using digital technologies for work, communication and buying certain goods and services; and the third group (25%, 88 people)—the millennials using digital technologies in certain spheres of their lives only if applicable.

The research results have demonstrated that young people (93%) understand the idea of augmented and virtual reality technologies. For the respondents who did not

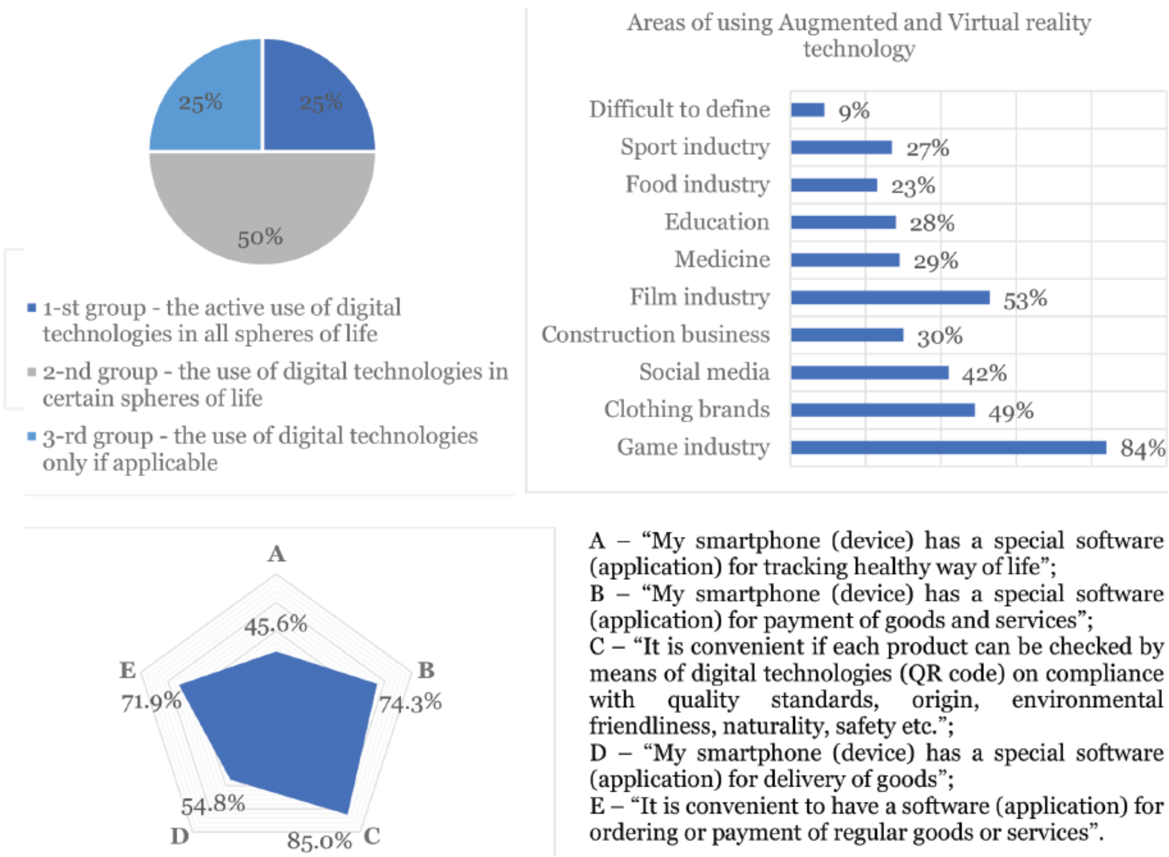

Figure 4.
Millennial responses to the use of digital technologies in different spheres of life (pilot research data).

know these technologies, the researches clarified the idea and demonstrated the variants of their application on definite examples. As for possible sphere of application of AR/VR technologies, it was established that most of respondents associate augmented and virtual reality with the game industry (84%), film industry (53%), clothing brands (49%) and social media (42%). Simultaneously, millennials less perceive the above-mentioned technologies in the food industry (23%), sport industry (27.5%), education (28%), medicine (29%) and construction business (30%). Only 9% of respondents could not define the place of AR/VR technologies in their everyday lives.

During the research, the respondents also evaluated statements characterizing their perception according to the scale: 0 points—strongly disagree with the statement; 2.5 points—rather disagree; 5 points—difficult to define (neutral position); 7.5 points—rather agree with the statement; 10 points—strongly agree. It helped to find out that most millennials (85%) wish to have an opportunity to check goods and services using digital technologies (QR code) on compliance with quality standards, origin, environmental friendliness, naturality, safety, etc. Most respondents (over 70%) have a special software for the payment of goods and services in their smartphones and wish to install an application for ordering and payment of regular goods and services. A half of young people (54%) use a special software for delivery of goods and only 45% of respondents use special applications for tracking healthy way of life.

According to the results of the survey, it was found out that all respondents visited online marketplaces, and 95% of them bought goods or services online. One-third of millennials (34%) buy goods on marketplaces monthly. An additional research allowed to reveal that 95% of young people agree to buy a product if it has a confirmation of authenticity from a brand manufacturer. Therefore, a negative stereotype

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about sales of fake products on marketplaces can be corrected by placement of detailed product characteristics and establishment of trustful open relationships with customers and partners.

2.5 Directions of marketing management innovation development

Marketing management innovation depends on the development of digital technologies, as they form a new lifestyle and change a view of a society creating competitive benefits for companies. Globalization and technologies have become two main factors, which define relations inside a society nowadays [17]. Correspondingly, the up-to-date marketing management strategy is grounded on multivariate choice of solutions regarding the use of definite innovative developments. That is, for realization of successful activity in digital transformation of business and society, a company permanently has to monitor the market and new tools, analyze customer needs and wishes, and maintain efficient communication with its partners.

Among the main marketing management innovation technologies can be distinguished: (1) artificial intelligence; (2) augmented and virtual reality; (3) neuromarketing and (4) MarTech. Further, we will consider them in detail.

The first innovative technology is the formation of artificial intelligence that is favorable for a company's uninterrupted interaction with customers, partners, employees and a society as a whole and helps to foresee peoples' intentions in different spheres of their lives and in different conditions. Artificial intelligence analyzes data and profiles, forms algorithms for better interaction and communication, systematizes required data providing maximum effectiveness and speed of making managerial solutions. In their activities, companies can use different variants, such as:

- voice processing technologies (e.g., virtual assistants for employees, partners and customers, which accompany the fulfillment of established tasks, handle orders, invite to joint events, recommend certain goods or services, evaluate effectiveness and loyalty);

- text processing technologies (e.g., virtual assistants, which reveal conflict situations and form algorithms of their solutions, develop marketing campaigns or different modifications of products basing on analysis of texts in social media, develop, analyze and reply to requests of customers, employees or partners);

- image recognition and processing technologies (e.g., recognition of faces to run certain business processes, definition of a health status grounding on mixing analysis of personal data with environment status data, analysis of images for a search and proposals of analogous goods, services or ideas);

- solutions making technologies (e.g., comparison of different alternatives for choosing a more efficient managerial decision, drawing up of an individual plan for personal development, career development, achievement of certain goals, motivation or rest).

The second innovative technology is augmented and virtual reality. Virtual reality is based on computer modeling of a three-dimensional image or environment where a human can interact with it if put on a special equipment (glasses, liens or helmet with a screen, a costume equipped with sensors). Augmented reality is a technology applying a computer reflection of imaginary additional product, idea or environment on a real image of a user, object or locality. Companies apply augmented and virtual reality technologies to design a customized product packaging (story living), and demonstrate test products under the real conditions of use (try before buy, location-based integration) [18–20]. To evaluate the effectiveness of implementing AR/VR technologies in marketing management, the following indicators are used: time of use, a number of actions, interaction with a content, a heat map, behavioral style, data of surveillance cameras, motility, quality of actions, voice timbre and modulation, tracking of eyes and body movements, understanding of further actions (preventions).

The third innovative technology is neuromarketing, which grounding on neurophysiological human behavior correlates and allows measuring human physiological and neuron signals to receive more clear representations about their motivation, wishes, decisions, etc. [21]. A neuromarketing technology combines a set of ways and methods of neuroscience and psychophysiology, namely, study of a brain, psychophysical reactions and behavioral features of a human. The mentioned researches are used in marketing management to analyze behavior of employees, partners, customers in different situations and conditions. The main neuromarketing tools can be conditionally divided into three groups [22–26]: (1) study of metabolic activities in brain (positron emission tomography and functional magnetic resonance imaging); (2) study of electrical activities in brain (transcranial magnetic stimulation, electroencephalography, magnetoencephalography, steady-state topography) and (3) study of physiological reactions (fixing of galvanic skin response, cardiovascular system, eye movement, contractions of facial muscles). Characteristics, advantages and disadvantages are given in **Table 2**.

The fourth innovative technology is MarTech combining marketing and technologies for gathering data on internal and external environment of a company. The choice of MarTech tools is an important component of development and realization of a company's successful strategy that permits to provide the optimal use of resources and harmonization of business processes. However, a tool must not substitute a strategy and implementation of digital technologies must not be just to pursuit technologies. The main MarTech tools can be conditionally divided into four groups [6]:

1. the management of data and digital assets of a company—the technologies, which store, control and maximally use digital data of a company to trace effectiveness of all business processes of marketing management and key performance indicators (KPI);

2. the management of relationships with customers—the technologies, which allow to control required structured data to maintain relationships with customers and partners;

3. the management of company's resources in separate spheres (marketing, financial, industrial, logistic, etc.)—the technologies, which are used for digital planning, administration, coordination and control of certain resources and combine data, procedures, tools and employees;

4. the management of social media and content—the technologies, which accumulate and analyze data of social media platforms to improve communication processes and increase recognizability of a company, a brand, a product, a service or an idea in a society.

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Neuromarketing tools	Characteristics	Advantages and disadvantages
(1) Study of metabolic activities in brain		
Positron emission tomography	A method of medical radioisotope diagnostics grounding on application of radiopharmaceuticals being isotope-labeled and positron radiating. Using special equipment, decay of radionuclides is traced and metabolic activities in human brain are studied.	Advantages: a wide research spectrum; significant detailing of results, high-resolution anatomical images Disadvantages: high cost, a need in highly qualified specialists, psychological stress for an object of research, insignificant radiation effect
Functional magnetic resonance imaging	A method of medical diagnostics grounding on measuring hemodynamic responses caused by neuron activities in human brain. Using special equipment, correlation of cerebral blood flow and neuronal activity is traced	
(2) Study of electrical activities in brain		
Electroencephalography	A method of medical diagnostics grounding on graphical registration of biopotentials of human brain that permits to analyze physical maturity and state, general cerebral activity and its character. Using special equipment summarized, bioelectrical activity in human brain is fixed and analyzed	Advantages: a wide research spectrum; significant detailing of results, equipment mobility Disadvantages: limited resolution images, a need in highly qualified specialists, psychological stress for an object of research
Magnetoencephalography	A method of medical diagnostics grounding on measurement and visualization of magnet fields emerging as a result of electrical activity in human brain. Using special equipment helps to localize neuronal activity sources in time and space	
(3) Study of physiological reactions		
Fixing galvanic skin response	A method of diagnostics grounding on a human peculiarity to sweat while anxiety or experiencing other strong emotions. Using special equipment, the data on electrical conductivity of skin are fixed and interpreted into a conclusion about an emotional state of a human	Advantages: equipment mobility, low cost, significant detailing of results, a possibility of mixing with other tools Disadvantages: limited resolution research, a need in highly qualified specialists, psychological stress for an object of research
Fixing cardiovascular system response	A method of diagnostics grounding on monitoring of changes in heart rate, blood pressure and vascular tone. Using special equipment, the data on cardiovascular system are fixed and interpreted into a conclusion about a change of attention and emotional state of a human.	
Fixing eye movement response	A method of diagnostics grounding on video fixation of gaze direction, size of a pupil, duration of gaze delay. Using special equipment, the data on eye movement are fixed and interpreted into a conclusion about concentration of attention on the object, the order of data revision.	
Fixing contractions of facial muscles	A method of diagnostics grounding on monitoring of contractions of facial muscles. Using special equipment, the data on individual movements of facial mimic are fixed and interpreted into a conclusion about certain emotions or feelings of a human.	

Table 2.
Main neuromarketing tools [21–26].

Lately, the tools for the management of social media and content have been developing most actively. At the market, there are a large number of social platforms having a great many users, especially among millennials. Some of media platforms are universal and are spread all over the world, such as Facebook, Instagram, Twitter, TikTok, Pinterest, LinkedIn. But most of them have a certain specific and are popular among different target audiences or in definite regions and countries.

Among the most spread MarTech tools for the management of social media and content can be distinguished as follows:

- Google Analytics, which enables to verify the effectiveness of a marketing strategy at different levels of interaction with customers, partners and different audiences to accumulate and analyze databases;

- Sprinklr and Kontentino, which make it easier to work with social media and help a company to minimize staff loading in this sphere;

- Buffer, which permits to manage posts in different social networks to keep several online profiles from one information panel, to plan posts in advance and trace statistical databases;

- ManageFlitter, which administrates the management of Twitter subscribers and finds influencers, allows to cover more followers and plan posts, defines frequency of posts and analyzes statistical databases;

- Buzzsumo, which helps to monitor new tendencies, demonstrates most popular materials and trends, searches for influencers, recommends up-to-date social media platforms and materials for a target audience, defines an average number of posts by certain topics and forms detailed analysis;

- Canva, which permits to create a visual content for social networks and graphical design based on professionally developed templates and availability of various convenient tools;

- Bitly, which generates URL addresses with a limited number of signs and measures links and URL clicking indicators;

- Brandmaker, which helps to develop marketing campaigns of a company, calculate budgets, measure results;

- Contentpepper, which uses automated processes to generate company content by means of Content Management System (CMS), and send materials to a target audience to different websites and communication platforms.

When planning implementation of any digital technology, managerial staff's first steps are queries in search engines, comparison of sets of functions and prices, discussing advantages and disadvantages of a certain technology with professionals, testing a free demo version for checking the compliance with goals and specific of a company [27].

Different packages of software and platforms can be compared by their features, but a real value of software for marketing management lies in a strategy and approach to the achievement of key goals of a company or desirable end results. Before implementing a definite digital technology in company's activity, it must be harmonized with a mission, vision and strategy. Tools, equipment and systems cannot be in conflict with each other or double certain spheres and business functions. Managerial staff has to carefully study all details, evaluate advantages and disadvantages of implementing a new technology, define opportunities and threats and only after that they must make an optimal managerial decision, which will concern company's business processes, employees, partners, customers and even a society.

3. Conclusions

Considering a rapid progress of digital technologies, needs and wishes of a society are permanently changing. It determines the importance of implementing innovative marketing management tools in company's business processes to solve a wide spectrum of tasks connected with a necessity of maintaining successful activity at the market. For complex evaluation of a company development status, now it is not enough for managerial staff to have the key economic quantitative indicators enabling to calculate expenses, revenues, incomes by separate operations, products, business units or processes. They have to be completed by qualitative indicators, which will help to define consumer priorities, staff loyalty, partner reliability, product positioning, uniqueness of goods or services, social recognition, etc. Consequently, the main goals of innovative marketing management conquering positions at the markets, which have not been developed yet, and increase of presence at already existing ones based on intellectual property, investments in research and development, innovative management methods, digital technologies in the care of employees, consumers, partners and a society as a whole.

Nowadays, the main marketing management innovations are connected with implementation of artificial intelligence, neuromarketing, augmented and virtual reality, marketing technologies MarTech in business processes of functionality. These technologies can be combined and applied in different spectrums of company's activity or various spheres of human life. Particularly, it can refer to millennials. The use of digital tools allows to analyze huge databases, detail results, develop preventive actions, predict future trends, test products, equipment or software, foresee consequences of decisions, find optimal variants of problem solutions, etc. Besides, innovative technologies help to study real requirements and wishes of people, reveal deep-seated needs and motives, balance different life spheres, test new ones, change habits, gain knowledge and skills, etc.

Therefore, marketing management and technologies are a certain symbiosis of people's decisions and digital data. That is why correct choice of digital tools in marketing management is impossible without clear understanding of a vision, mission, strategy and corporate values by managerial staff and employees. All these determine a choice of technologies and successful implementation due to consequent passing through five main stages. At the first stage, managerial staff accumulates the available actual information on different technological tools and solutions, analyzes their compliance with a mission, vision and strategies of a company, studies parameters of integration with other systems. At the second stage, an optimal technology is chosen that best meets business goals and tools start being implemented at strategic level. Implementation of new technologies at this level allows a company to evaluate an innovation focus, if it is necessary to correct, and define skills and competences required for staff's work. At the third stage, gradual implementation of innovative technologies in business processes of a company and active cooperation with IT specialists at each operation takes place. The main goal of technological marketing management at this stage is reduction of staff's time spends on training or advanced training due to creation of intuitively understood interfaces for users and digital materials to help in solving standard task algorithms. At the fourth stage equipment, devices, platforms and tools are integrated into one system. A new system has to cover all actual business processes and contains required functionality for perspective directions. At the fifth stage, managerial staff monitors and evaluates effectiveness of business processes, analyzes advantages and disadvantages, develops improvements and recommends new solutions to increase marketing management effectiveness. Thus, implementation of digital technologies in business processes of a company significantly depends on a team's motivation and belief in success of innovations.

Establishment of factors of digital transformation impact on business and society to form innovative approaches in management in accordance with the modern realities is a complex comprehensive problem. To solve this problem, we carried out a research, which can conditionally be divided into five stages: At the first stage, the main factors of digital transformation in business and society were established; at the second stage, the basic hypotheses of innovative marketing management were formulated; at the third stage, up-to-date marketing management concept in digital transformation of business and society was developed; at the fourth stage, the use of digital technologies by millennials in their everyday lives was analyzed; at the last fifth stage, the main four directions of marketing management innovation development were defined. The conducted research enabled to reveal that fast and active implementation of innovative tools by certain companies can lead to the occurrence of covert and open conflicts between millennials and the older generation that will have a negative impact on corporate culture and psychological climate in company staff. Therefore, innovation technologies and management model in digital transformation of business and society have to be implemented gradually in compliance with strategic priorities defined by a company.

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Chapter

Perspective Chapter: Data as Currency - On the Impact of ICTs and Data on the Saudi Economy and Industrial Sector

Kinda R. Dahlan, Ahmed A. Badawi and Ali Megahed

Abstract

In delineating successful digital application models in Saudi Arabia, this chapter explores the country's digital readiness to further expound its industrial strategic goals. We argue that a gap exists between the availability of data and technology and the availability of human capabilities that can facilitate the meaningful processing of industrial data. Data deluge brings substantial challenges in the collection and management of massive amounts of unstructured data towards decision making. Likewise, unprecedented production of information exceeds the ability of authoritative bodies to create regulations and policies that can keep up with these transformations in the nature of work. We explicate the impact of well-timed policies (fiscal and monetary), prediction of long-term structural changes in the industrial sector, industrial strategy formulation practices, and examine the economic studies and analysis of sustainable development in these areas.

Keywords: digital transformation strategy, Industry 4.0, data governance, digital readiness, Saudi Arabia

1. Introduction

The industrial sector plays a critical role in solving society's most pressing issues—from resource preservation, to climate change, to social stability. The adoption of industry 4.0 technologies and practices utilize data and favour circular production models that allow for better decision making, optimized resource usage and energy consumption. This requires round-the-clock data collection and adapted analytical frameworks managed under well-timed policies, both fiscal and monetary. To this effect, Saudi Arabia began turning its attention towards a sustainable model of economic growth aimed at propelling the Kingdom towards a new development trajectory guided by its national strategic vision—*Vision 2030*. This trajectory seeks to diversify national economy and promote industrial innovation, social well-being, and progress. With new modernization strategies in place, attention has been placed on developing a model of intricate economic systems, equipped with the latest technologies, for the industrial sector to reduce its dependency on oil and petrochemicals, and where data access and sharing is at the heart of innovation and successful digital transformation.

In delineating such digital application models in Saudi Arabia, this chapter explores the country's digital readiness to further expound the potential to achieve its industrial strategic goals. We argue that although the Kingdom has invested heavily in ICTs and telecoms infrastructure, a gap exists between the availability of data and technology and the availability of human capabilities that facilitate meaningful processing of industrial data. That is, there are two main hypotheses driving the research outlined in this chapter: (1) data deluge brings substantial challenges in the timely collection and processing of massive amounts of information and unstructured data towards decision making; (2) the unprecedented production of information exceeds available human capabilities and the ability of authoritative bodies to create regulations and policies that can keep up with these transformations.

This chapter explicates the impact of well-timed policies (fiscal and monetary), prediction of long-term structural changes in the industrial sector, industrial strategy formulation practices, and examine the economic studies and analysis of sustainable development in these areas to address these challenges. It begins with a description of the research methodology (Section 2), followed by an analysis of the Saudi national strategy detailing its aspirations for the industrial sector, the state of digital readiness in the country, and the availability of human capabilities to match these aspirations (Section 3). The following section, Section 4, provides an overview of how the COVID19 pandemic catalysed Saudi digital transformation efforts, and discusses the economic impact of data on the industrial sector given the global crisis. Section 5, highlights the successful utilization of ICTs in Saudi Arabia in light of further potential for development, and explores the alignment of these applications with the Saudi industrial strategic Vision 2030. Finally, we conclude with the potential of applying such technologies to the industrial sector by reviewing the macroeconomics of well-timed policies in this scope.

Our findings reveal that there are limitations in educational initiatives targeting digital upskilling to meet the needs of the aspirations of the national strategy. We have found that there are innovative efforts to address this gap within the Kingdom through various government-backed programs. We also observed that though foreign investment is gaining traction, knowledge transfer and exchange remains limited via these investments. Research also shows that traditional formal education remains the dominant national model in the Kingdom, limiting opportunities that arise from other educational streams. In conducting this research, the hope for this work is to highlight successful achievements to then draw attention to strategic areas of improvement over the next period, such as the production of globally competitive ICT products and services, alternative educational models, and directions to enhance the utilization of available data across different sectors and economic activities.

2. Method

The methodological goals of this research are to examine how aligned Saudi's strategic objectives are with its reported digital readiness and to shed light on its digital transformation journey in order to make recommendations for further development. The research methods adopted thus follow a *content analysis* framework whereby it is defined as "a careful, detailed, systematic examination and interpretation of a particular body of material in an effort to identify patters, themes, biases, and meanings"

[1]. As such, the axiology informing this normative methodology is based on a *critical hermeneutic* approach that establishes media resources (such as websites) as displays of society's most pressing concerns, interests, and values [2]. Within this scope, reasoning behind this research is *inductive*, whereby it moves from specific observations in data and information practices towards broader generalizations and theories. That is, we utilize a *purposive sampling* strategy of data [3] to analyse our findings *inductively* vis-à-vis a content analysis [1]. A methodology designed in this way establishes a regulatory framework that facilitates the extrapolation and assessment of extant information for the purpose of arriving at, and validating, new knowledge [4].

Given that this is a country-specific study, the body of material utilized is based on a non-probability sampling method of data sourced from two main resources: official Saudi Government databases and digital readiness indices published by not-for-profit (NFP) organizations. This is then supplemented by peer-reviewed research accessed through several databases. Saudi official sources include resources available through websites that end with *.gov.sa* in their URLs, while NFP resources include the UN Public Administration Network's (UNPAN) e-Government Readiness Index [5], the FitchSolutions Industry 4.0 Market Maturity Index [6], and the International Telecommunications Union's (ITU) Digital Opportunity Index (DOI) and the ICT Opportunity Index (ICT-OI) [7]. This allows for a comparative analysis between globally-available assessments of the Kingdom and its reported national objectives and achievements.

Because websites are media outlets, the researchers opted to use communication research methods in the research design. That is, communication research methodology provided a blueprint to examine *messages* that are transmitted through one or several components of the traditional model of communication: messages, people, channels, and contexts [1]. This includes "studying how new technologies affect the flow of information" where data is certainly a by-product of this process and thus central to the research at hand [1].

Further research was consulted in the literature review to include studies on Saudi Arabia. Because the sampling method is a non-probability purposive sampling, only materials that mention, discuss, or reference Saudi Arabia and related fields in ICTs, economy, data, and industrial manufacturing were selected; and because the corpus of this research is country-specific, the research discourse scheme is based on a discourse of "Saudi Arabia," "Industry 4.0," "technology," and "digital readiness." This includes word variations including *Saudi, Saudi Arabia, KSA, the Kingdom of Saudi Arabia, The Kingdom, Arabia, technology, ICT, ICTs, digital, data, Industry 4.0, industrial economy*. To better frame this research to fit the parameters of our research problem, a complimenting precedent-setting criterion was applied. Terms and sentences that denote national development, strategic objectives, public opportunity and achievements were taken into consideration in the selection process of journal articles. This non-probability purposive sampling scheme provides a reliable and reproducible method to examine other country-specific material in a similar fashion [8].

3. Saudi Arabia digital readiness and development

It is important to point out that there is no one-size-fits-all method to measure data and ICT readiness—let alone a means to determine the value of data as currency in general. Digital readiness for Saudi Arabia is determined from data accessed through several indices. Alongside these indices, this section examines the strategic national

Vision, popularized as *Vision 2030*, key strategic partnerships with tech-relevant companies, telecommunication infrastructure, data governance and accessibility, and available human capabilities. The following sub-sections delineate these key areas further.

3.1 The Saudi national strategy: vision 2030

Saudi Vision 2030 is a set of reforms categorized under 3 pillars, with 6 objectives that are translated into 11 vision-realization programs. Each objective under each pillar has a set of sub-objectives totalling to 27, which are then further divided into 96 strategic objectives. There are two key objectives outlined under each of the 3 pillars. The first pillar, *a vibrant society*, aims to (1) improve Saudi standard of living, through world-class healthcare and education systems, and (2) preserve and celebrate cultural heritage, and national identity. Some of its goals include increasing Umrah capacity, enhance entertainment avenues and increase spending in this sector, improve Saudi's ranking in the Social Capital Index, and increase average life expectancy. The second pillar, a *thriving economy*, has two more objectives: (1) to grow and diversify the economy, and (2) to increase employment and unlock business opportunities. The final pillar, an *ambitious nation*, seeks to (1) create a high-performing government to empower citizens, private sector, and not-for-profit organizations, and (2) to enable social responsibility. Goals under this pillar include raising Saudi's rank in the e-Government Survey Index from 36 to the top 5, raising Saudi's ranking in the Government Effectives index from 80 to 20, and increasing non-oil government revenue [9].

Digital transformation reforms and objectives are at the core of the second pillar, a *thriving economy*. According to the vision [10]:

> *"A sophisticated digital infrastructure is integral to today's advanced industrial activities. It attracts investors and enhances the fundamental competitiveness of the Saudi economy.*
>
> *We will partner with the private sector to develop the telecommunications and information technology infrastructure, especially high-speed broadband, expanding its coverage and capacity within and around cities and improving its quality. Our specific goal is to exceed 90% housing coverage in densely populated cities and 66% in other urban zones. We will also develop building standards to facilitate the extension of broadband networks.*
>
> *We will strengthen the governance of digital transformation through a national council. Additionally, we will improve our regulations and establish an effective partnership with telecom operators to better develop this critical infrastructure. We will also support local investments in the telecommunications and information technology sectors."*

Through its 11 vision realization programs, which include the Human Capability Development Program (CDP), the Public Investment Fund Program (PIF) the National Transformation Program (NTP), and the National Industrial Development and Logistics Program (NIDLP), Saudi has outlined key objectives relating to ICTs, technology, data accessibility, and industrial development. This includes, localizing technology and knowledge, building human capabilities, developing technological infrastructure, and facilitating e-services.

NIDLP for example, aims to transform the Kingdom into a leading industrial powerhouse as well as an international logistics platform in several sectors with a focus on applied internet technologies (a.k.a. Industry 4.0). This is meant to create more jobs, enhance trade balance, and maximize local content. NIDLP covers 4 sectors: industry, mining, energy, and logistics. PIF promotes local and international investment, fostering economic partnerships to deepen its impact beyond Saudi-borders, and bolstering various existing sectors with the latest technologies, including: healthcare, manufacturing, energy, and smart cities.

Another key component of the Saudi Arabian Vision 2030 strategy for digital transformation is to "realize a smart government" through the Digital Government Authority. The Saudi government recognizes the value of data for a knowledge-hungry economy and a growing immersive e-commerce ecosystem that is charged by its, predominantly, young population. As of 2020, and summarized in **Figure 1**, the largest age group of the 35+ million Saudi population is the 35 to 39 group [11]. Of the total population, 69% are younger than 40. This age group is technologically literate and make up the bulk of users targeted by e-government programs. In response, the government has developed a national strategy for digital transformation [12] and has been investing heavily in telecommunication systems and Information and Communication Technologies (ICTs) over the past decade.

For Saudi Arabia to achieve such ambitious goals, outlined in Vision 2030 [9], to improve public services, diversify its economy, and identify societal needs, it must also incorporate processes that leverage on data access and analytics. In line with this new direction to modernize and grow its industrial sector, Saudi Arabia has established the Saudi Authority for Industrial Cities and Technology Zones (MODON), funded several mega projects in the form of industrial cities (e.g., Oxagon), smart cities (e.g., NEOM), and programs (e.g., NIDLP). Technology is central to these new initiatives, shaped by unprecedented capabilities and applications of Industry 4.0 and Artificial intelligence (AI) technologies such as machine learning,

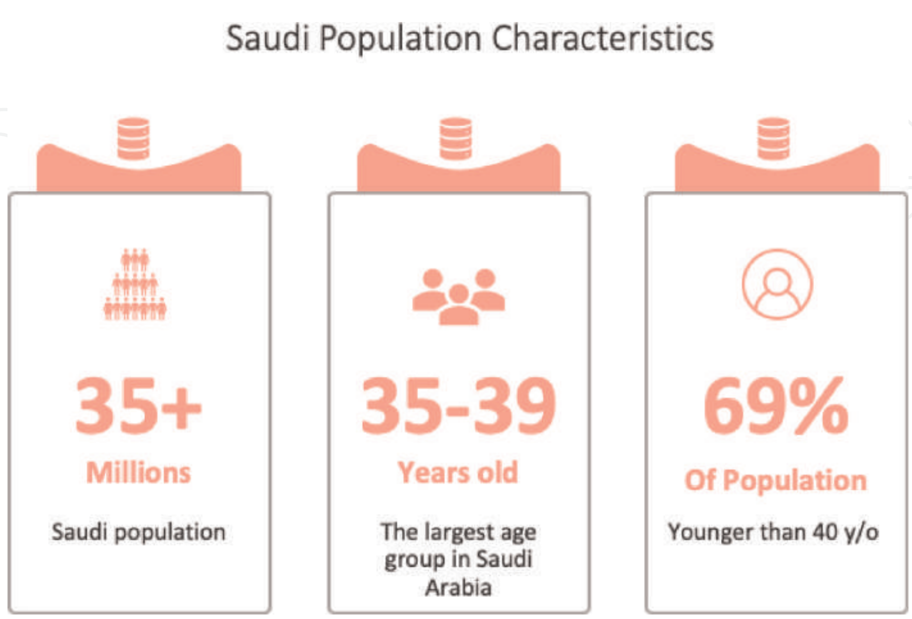

Figure 1.
Saudi Arabia Demographics. The figure depicts highlights the total population, largest age group, and percent of youth within population in 2020. Copyrights: Ali Megahed 2021.

internet of things (IoT), and Big Data analysis. Immediately, this offers growth opportunities for less data-intensive fields such as manufacturing and construction [13]. This trajectory also emphasizes sectoral digital transformation strategies reliant on data that are valid, reliable, and sustainable.

As process, digital transformation creates disruption that triggers strategic responses to value-creation paths in industry and manufacturing operations. It also impacts structural changes and surfaces new organizational barriers affecting process outcomes. The industrial sector in Saudi Arabia for instance, through MODON, is increasingly adopting disruptive technologies to utilize the abundance of available data as part of its strategic aspirations to compete in a data-driven global market. Overall, Saudi industry is a key driver in regional economic and social transitions currently taking place. Alongside its digital transformation strategy, the Kingdom has announced plans for its green renewable energy initiative as of 2021 [14].

In order to remain an engine of prosperity, the Kingdom is investing massively in these areas and in moving toward Industry 5.0 technologies with a vision that aims beyond efficiency and productivity. Compared to Industry 4.0 (i4.0), Industry 5.0 (i5.0) emphasizes research and innovation towards human-centric and sustainable industry. Multiple Saudi entities have been looking at educational partnership through signed agreements with academic institutions to transition from i4.0 to i5.0. King Abdullah University of Science and Technology (KAUST) and King Abdulaziz University are at the forefront with active agreements with international academic institutions and with a variety of government research entities to support and implement research projects that serve the industrial sector and contribute to creating a knowledge-based economy through scientific research. The Saudi government has also signed an agreement with the World Economic Forum (WEF) to establish an in-Kingdom branch of WEF's Centre for the Fourth Industrial Revolution, the fifth of its kind worldwide [15]. This involves cooperation between WEF and King Abdulaziz City for Science and Technology (KACST) to manage the center, which aims to develop mechanisms, plans, and applications for Industry 4.0 nationally. This includes awareness and governance plans that support the adoption of technology and best practices regionally and globally, positioning Saudi well within the global 4th Industrial Revolution network, along with countries such as India and China. The center also acts as a platform for further cooperation opportunities with other government agencies and institutions to develop solutions and support capacity building, skill advancement and other competencies as they relate to Industry 4.0 [16].

3.2 On Saudi data governance and accessibility

The successful implementation of the Saudi national strategy and its programs relies heavily on data and information. This section describes critical issues surrounding data governance and accessibility in Saudi Arabia.

Ostensibly, data are critical for production. Unlike labour and capital—or oil, in the context of Saudi Arabia—data are a non-depletable resource that can be reused again and again for different purposes, in different contexts. The value of data, arguably, increases the more it is used [17]. For Saudi Arabia, the use of its public social data, and the integration between different applications, has resulted in the creation of an array of government services. Even so, despite being non-depletable, data can become less relevant with time, thereby reducing its value. Data characteristics have a direct corelation to their value. Data that cannot be used, are inaccessible, or otherwise cannot be parsed or processed have little value.

Understanding these characteristics and employing the right human capabilities can turn a single data point, with little value, into a repurposed value-multiplying commodity that has meaning and context when "aggregated and analysed with other relevant data" [18]. Accumulating data enhances productivity and enhances decision making. Opening it up for greater access has the promise of greater innovation when more firms are able to use it and compete in generating knowledge.

In the industrial sector, the high-capital intensity and necessary control over operating costs stands to benefit from automation in remote areas through the utilization of sophisticated technological solutions that produce reliable and unbiased information. As it stands, and given the harsh desert climate and inaccessible remote terrain in Saudi Arabia, such remote areas are typically manageable by "powerful companies" that are capable of bearing the risks of carrying these projects out—financially and technically. More data can cut down cost, opening up further opportunities for small and medium sized entities (SMEs) to compete [17].

Needless to say, companies that generate large datasets have incentive to hold on to their assets, stifling the potential of open access data for fair competition and innovation. This not only reduces the social benefits of data access, but also threatens privacy and ethical usage of data. As there are types of data, utilized for different purposes, there are different types of disadvantages. For personal information, generated through social data, an individual is at a disadvantage when her/his/their information is transacted in an unsafe way or without their knowledge. Protecting such information is expensive and complicated, and for the most part, the law has not caught up with the complexities surrounding data. Governments, in turn, should work towards deploying policies that encourage data sharing to promote competition and innovation, and to protect privacy.

Big Data for instance, is rapidly becoming a common approach as the range of variables for industrial indicators are expanded. However, access to such data depends on (a) access to sizable data, and, of course, (b) data that is optimized through cloud computing and services. This means that cooperation between various entities, especially across borders becomes essential. Although countries are moving towards centralizing information to make use of "the cloud" (e.g., European Union Cohesion Policy [19, 20]) Saudi has chosen to adopt an edge model by imposing strict localization regulations for government and public data [19].

This comes in light of several strategic steps that were taken to ensure the privacy and protection of personal data as the country competes to become a contender in efficient implementation of Industry 4.0, AI, and in growing its data assets. In 2020, SDAIA announced its National Strategy for Data and Artificial Intelligence (NSDAI), and in 2021, the National Data Management Office (NDMO), promising a strategic roadmap for disruptive technology integration into the healthcare, energy, logistic, and government sectors, and regulations for the management and digitization of data as a national asset[1]. this enables the protection of personal and sensitive data, by developing required strategies, laws, policies and regulations to ensure their application and compliance. Such an integration brings into focus major issues of privacy, competition, and stability.

That is, traditionally, these issues have been handled by separate ministries, and only recently subject to integrated approaches to effective data policy that manage complex trade-offs. The NDMO [21], established in 2019 as a sub-entity of SDAIA,

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[1] Find out more about the NDMO at https://sdaia.gov.sa/ndmo/?Lang=en.

released a variety of regulations to oversee and regulate data management across all government and semi-government entities. Similarly, the personal data protection law (PDPL), issued in September 2021, is the first of its kind [22] in the country. It is proceeded by the 2020 Communication and Information Technology Commission (CITC) regulations surrounding user data privacy within the telecoms sector [23]. Through a royal decree No. (M/19) and cabinet resolution No. (98), the PDPL is designed to protect the privacy of personal data and regulate data sharing practices to prevent privacy breaches and abuse of information given how quickly data sharing happens, how opaque data market are, and the more digital literate the country becomes. The law outlines obligations, limitation, accountability, and penalization policies surrounding data use. It also draws out the roles and responsibilities for data collectors and users to register, update, and maintain data processing records and rights. This also applies to non-Saudi companies operating within Kingdom or those processing Saudi data.

Saudi also applied restrictions on cross-border data transfers that require approval for data processing by designated government authorities. Any data controller must register with SDAIA through a paid membership plan. As mentioned earlier, Saudi has one of the strictest localization laws globally. It requires foreign companies without local presence to appoint a local representative that is licensed to process its data within Kingdom by 2023. This new law encompasses the processing of personal data which includes financial, genetic, credit, health, and otherwise private information as set forth by the local Shari'ah law.

According to SDAIA, further regulations are to be set as the Kingdom completes its inventory of data needs and requirements. What is of interest here is that the law requires companies to inform SDAIA of any breaches or data leakage, which then notifies concerned subjects. When it comes to the associated penalization framework, the law outlines up to 2 years of imprisonment coupled with fines of up to SR3 million Saudi Riyals (Approx. $ 800K USD) [22].

3.3 On Saudi strategic tech-partnerships

When it comes to partnerships, Saudi Arabia boasts several strategic partnerships regionally, globally, as well as across various national governmental and private entities as touched upon in Section 3.1. It began with the country's National Center for Artificial Intelligence (NCAI) signing agreements with China's Huawei and Alibaba Cloud to design AI-related Arabic-language systems. Saudi Arabia also has an agreement with IBM to implement blockchain applications for government and commercial services [5]. The Saudi Data and Artificial Intelligence Authority (SDAIA) also secured key strategic partnerships with The World Bank to help countries create "policies and initiatives that use AI to support national development and growth" [24]. These efforts focus on identifying gaps in readiness to accelerate the creation of AI policies and innovation that support sustainable development goals as well as newly-established governance frameworks. SDAIA also partnered with the International Telecommunication Union (ITU) to collaborate on designing AI applications for the sustainable development of new projects, initiatives, and activities to facilitate international cooperation and knowledge sharing that meet UN goals. In 2020, the Saudi Telecoms Company (STC) announced its partnership with US-based tech company Nvidia to build the Kingdom's first AI and deep learning cloud infrastructure, becoming the first cloud service provider in the region to offer AI-capabilities in the country [6, 24].

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3.4 On Saudi telecommunication infrastructure

In terms of its infrastructural readiness, Saudi Arabia is ranked amongst the top. Currently, it boasts a strong telecoms infrastructure that is imperative for the successful implementation of an Industry 4.0 ecosystem. According to a FitchSolutions report, the Kingdom has a robust 5G coverage as of Q2-21 [24]. All network operators offer 4G LTE services, while STC and Zain have launched 5G services in 2019. Opportunities that arise from a stable 5G network include long-term industrial growth prospects, especially in major connected and smart-cities initiatives. According to the report, "[n]ew investment in 'smart-cities' may bolster telecommunications connectivity in the country if implemented and lead to a faster uptake of advanced technologies in the kingdom" supporting the growth and development of AI in the country. At a glance, Saudi Arabia ranks second, after China, in terms of its investment in AI technology [5].

Partnering up with the private sector, the government succeeded in the provision of fibreoptic network coverage to more than 3.5 million homes in 2020, and overall telecom services to 100% of households [12], 99% of which are covered by at least 3G mobile network, and 98% covered by 4G network [7]. This includes broadband for 576k homes in rural and remote areas [12]. Worthy of note here is that Saudi "is one of only two GCC countries in which nationals outnumber foreigners, accounting for 69% of the population" [25]. The data comparing mobile and fixed telephone subscriptions is telling in that more and more individuals have access to smartphone technology, thereby access to the Internet [7] at 98% of the total population with Internet access. Saudi Arabia also boasts a youthful population that is expected to contribute to the uptake of new technologies and best practices, where the age range between 15-24 make up the majority of internet users since 2017 (99% [7], 93% for 25-75 years old; 92% for age group <15; no information is available about data access for the age group 75+). **Figure 2** summarizes the main strengthens of the Saudi telecom infrastructure as of 2021 in relation to its population.

Another Fitch report also highlighted the significance of access allocation by the Saudi Communications and Information Technology Commission (CITC) to approximately 23GHz of spectrum; "CITC will allow license-exempt access to the entirety of

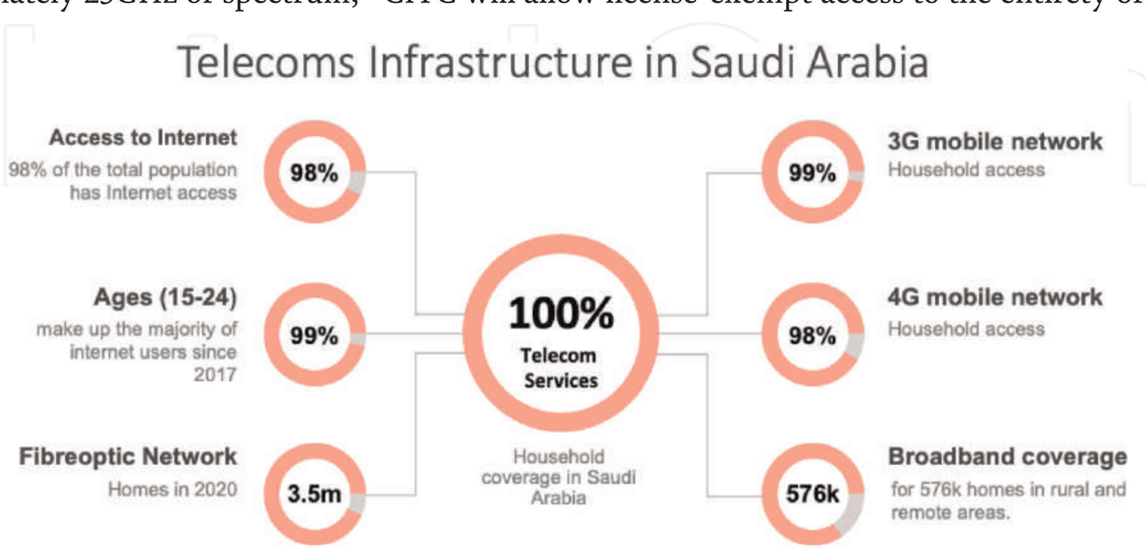

Figure 2.
Saudi Arabia Telecommunication Infrastructure at a Glance. The figure summarizes the main advancement in telecoms in Saudi Arabia as of 2021 where it boasts 100% coverage for all households. Copyrights: Ali Megahed 2021.

the 6GHz band, a move which is expected to facilitate the wider deployment of broadband services" [6]. This allocation of additional spectrum demonstrates the Kingdom's awareness of the importance of, and the intense demand for, data, which has escalated over recent years with the growth of Industry 4.0 technologies. This technological proliferation is expected to continue—especially in light of the pandemic, and facilitated by Saudi's digitization programs [6]. Operators such as STC will benefit from the development of new use cases for Internet-based technologies, bolstered by government support. This push for digital transformation will in turn raise the profile of diverse sector-led industries.

Another key achievement in developing the Industry 4.0 ecosystem is the development of technological regulations. CITC has successfully developed regulations for cloud computing, with guidelines that will extend to IoT and AI [6]. According to the FitchSolutions Industry 4.0 Market Maturity Index, Saudi Arabia comes in second regionally, "with a total score of 40.6 points out of a potential 100" [6]. The Kingdom also does relatively well in terms of "readiness to realize Industry 4.0." Analysis from the report shows that Saudi already leads regionally in the *demand* pillar of the index, showcasing its strong commitment to investing in disruptive technologies.

Saudi Arabia's technological and telecoms infrastructure enhances its appeal to tech investors globally through its readiness to deploy WIFI 6 [6]. This is significant because it has risen from a bandwidth-deficient market in only 5 years (since 2016), achieving a remarkable spectrum increase of 226% (from 340MHz to 1,110MHz) according to a MENA Telecoms Risk/Reward Index [6]. Saudi Arabia has paved the way as a pioneer and as the first country in the EMEA region "to designate 6GHz band completely for license-exempt use [6]. This also sets the stage for lucrative partnerships with operators and other entities to improve high-speed broadband coverage in unserved areas, allowing services to reach more factory and industrial sites: an "infrastructure development pipeline will bode well for national technological uptake over the coming decade" [24], whereby the number of enterprises and foreign investment will grow rapidly in the coming years.

The robust infrastructure is no surprise, given that Saudi is one of a handful of countries that mandates the localization of data to ensure data security and domestic digital infrastructure [19]. In fact, the more advanced data-oriented technologies become, the higher the expectations are for stringent data transfer restrictions to be embedded in cybersecurity laws and policies in order to safeguard data [19]. During the COVID19 pandemic, and as a result of infrastructural readiness, internet traffic rose by 30% in Saudi Arabia—doubling traffic through the Saudi Arabian Internet Exchange (SAIX). Internet speed in the Kingdom also increased to 109 Mbps in 2020 from 9Mbps in 2017. Likewise, Saudi successfully completed the expansion of network coverage at the Holy Mosque in Makkah to support annual pilgrimage and Umrah [12]—an annual religious event with high-intensity network usage, within a relatively small geographic space, during a narrow timeframe.

3.5 On Saudi digital index rankings

Different indices and reports exist for an array of data categories. While they diverge, there are common elements between them. The international community, through UN membership, recognizes the importance of the availability of proper indicators for the design and implementation of ICT and data policies that are efficient and effective in bridging the digital divide and aiding countries in utilizing technology to develop their industrial sectors better. According to the Tunis Agenda of the World

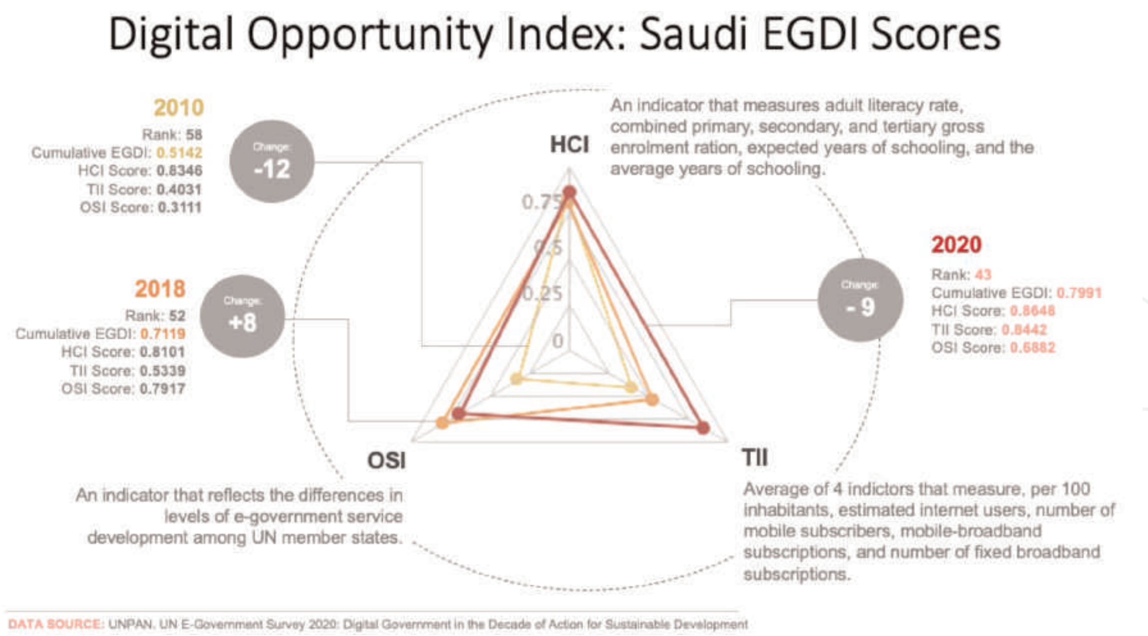

Figure 3.
E-government development (EGDI): Saudi ranking. The figure summarizes Saudi Arabia's e-government development scores for three indicators in 2020, out of 193 assessed countries, as per UNPAN data. Copyrights: Kinda Dahlan 2021.

Summit on Information Society, "[t]he development of ICT indicators is important for measuring the digital divide." [26]. Some of the key indices used in this analysis include the UN Public Administration Network's (UNPAN) e-Government Readiness Index [5], the FitchSolutions Industry 4.0 Market Maturity Index [6], and the International Telecommunications Union's (ITU) Digital Opportunity Index (DOI) and the ICT Opportunity Index (ICT-OI) [7].

In terms of e-government development (EGDI), summarized in **Figure 3**, Saudi ranked as *very high* in the latest cumulative EDGI report by the UNPAN Digital Opportunity Index [5], moving from *high* to *very high* rankings between 2018-2020 for the first time. Saudi is accompanied by 6 other countries (china, Kuwait, Malaysia, Oman, Turkey, and Thailand) in this ranking. Cumulatively, it ranks 43 at an EDGI score of 0.7991 as of 2020, compared to 0.7119 in 2018. Overall, the average EDGI in Asia is 0.5779, and in the Americas 0.5898 [5]. Saudi Arabia is joined by six other gulf countries in the very high EGDI group. At the top of the GCC countries, the UAE ranks highest as part of the V3 class, while Saudi sits at the top of the V2 class as of 2020. What is noteworthy is that the Kingdom secured its V2 placement under the *very high* classification rank, skipping V1, suggesting a rapid increase in development. This is also in light of the drop in the number of countries that were classified under the *high* category compared to previous reports [5].

Likewise, Saudi Arabia scored 0.8648 in the Human Capital Index (HCI), and 0.8442 in terms of the Telecommunication Infrastructure Index (TII). The HCI is an indicator that measures adult literacy rate, combined primary, secondary, and tertiary gross enrolment ration, expected years of schooling, and the average years of schooling. However, it does not measure digital literacy due to insufficient data. TII is an average of four indictors that measure, per 100 inhabitants, estimated internet users (KSA: 93.3%, compared to data from [7, 12]), number of mobile subscribers (KSA: 120), mobile-broadband subscriptions (KSA: 111.1), and the number of fixed broadband subscriptions (KSA: 20.24) [5]. As described earlier, due to its proactive response during the pandemic, the TII score for Saudi Arabia is anticipated to grow by the next report. Additionally, Saudi Arabia scored 0.6882 in the Online Service Index (OSI), following Kuwait, Albania, Portugal, and Armenia, and followed by Costa Rica, Ukraine, and Indonesia. The OSI reflects the differences in levels of e-government service development among UN member states.

3.6 On Saudi human capabilities

Reiterating from the previous section, Saudi scored 0.8648 in the Human Capital Index (HCI), a score higher than its OSI. This indicates that there is potential for further development in terms of its OSI ranking—should its HCI score be indicative of available human resources [5]. However, given that the HCI does not measure digital literacy, as indicated by the UNPAN methodology [5], there may as well be restraints in gaging the actual digital divide happening within the Kingdom, contributing to ostensible limitations.

Through a different index however, the ITU World Telecommunication/ICT Indicators Database [7], further insight on digital literacy can be assessed. This is summarized in **Figure 4**. According to the database, 21% of the Saudi population have advanced ICT skills, while 65% are armed with standard skills as of 2020. This is compared to 14% and 56% in 2019, respectively [14]. Advanced skills imply capabilities in computer program authoring using specialized programming languages, compared to standard skills, which refer to the use of basic arithmetic formulas and the use of computer applications (spreadsheets, presentations ... etc.), connecting and installing devices, and installing and configuring software. Notwithstanding, as of 2020, 61% of the population (compared to 68% in 2019) are said to have basic computing skills that involve the ability to send emails, copy-paste, and otherwise general information access and sharing practices [7].

Emphasising Vision 2030 objective, “[d]igital inclusion and leaving no one behind are high on the Kingdom's Government agenda” [27]. According to the Global Competitiveness Report published by the World Economic Forum in 2020 [27], Saudi Arabia has successfully implemented programs and initiatives that allowed it to compete in the top 10 countries in digital skills. The goal is to increase basic digital literacy from its current 61% to 90% by 2024. On par with these objectives, Saudi Arabia has

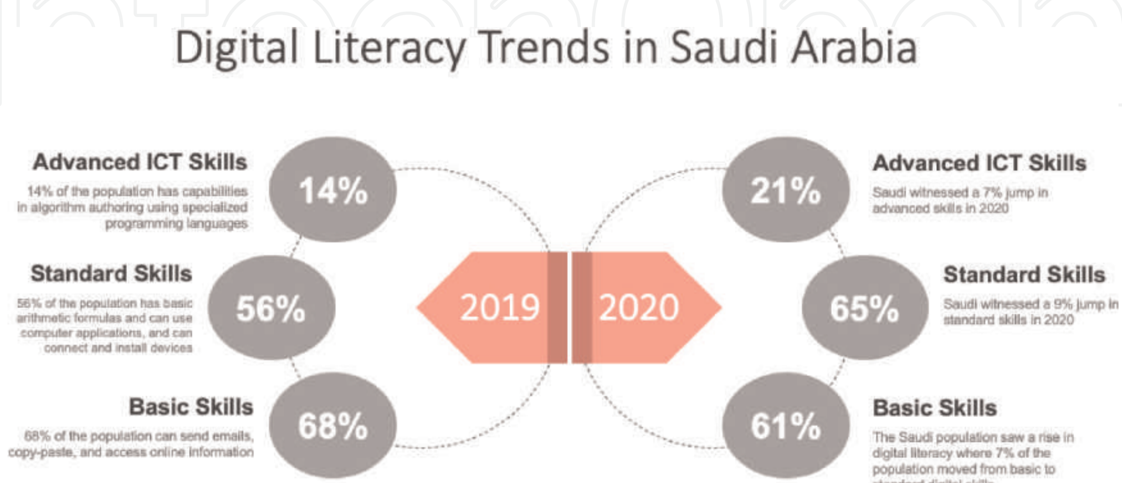

Figure 4.
Digital literacy in Saudi Arabia. The figure compares digital literacy development as it pertains to ICT skills within the general population between 2019 and 2020. Copyrights: Ali Megahed 2021.

also emphasized women empowerment through various programs that aims to enable women in both private and public sectors. The Kingdom has won the 2020 ITU Women Empowerment in Technology award [27]. This program is amongst several launched by the Ministry of Communication and Information Technology.

Despite this, data access and sharing practices remain well below potential within the population but is on a steady path of growth, and in contrast to the rapid advancements in e-government services [13]. This highlights the importance of raising digital literacy as a critical objective for the government to mitigate digital security and privacy risks. Although the Kingdom does impose strict data localization regulations to counteract this, without proper efforts to enhance digital literacy, data breaches and intellectual property rights violations pose an imminent risk. Some governments entities and private sector actors established various initiatives to counteract these possible risks. But according to the OECD [13], these efforts remain uneven across borders and sectors. One key challenge to these efforts has been in the utilization of Linked Data[2] [28] to implement interoperability between different governance frameworks. The gap between such frameworks (local, regional, national, and transnational) is stark. But Linked Data holds much promise in making it easier to locate information using ICT by creating connections between, and interlinking, data using web technologies, standards, and protocols as delineated in the next section.

Another challenge the exacerbates the need for advanced human capabilities, beyond the challenges of linking differing governance frameworks, is that new disruptive internet technologies such as cloud computing, social networking, GPS, sensors, satellites and smartphones facilitate unprecedented generation of large volumes of data—both simple and complex [29]. The biggest challenge here is in processing and making use of exorbitant quantities of data—namely Big Data— due to limitations in the capacity of conventional tools and processes to manage, store, and make meaningful connections from these data in reasonable time. Big Data in essence cannot exist without the "small 'complex' data" that validate them [28]. That is, the problem is in finding the connections between data types rather than the policies surrounding them; turning unstructured data to structured data. So, although automation holds the potential promise to simplify the management of large quantities of information—whereby, automation is a process that involves utilizing information and communication technologies (ICTs) to mechanize what traditionally requires manual labour [30]—it is not, yet, a tangible goal, given the current available human capabilities and the strict localization laws.

Automation requires the proper use of data in order for processing to occur seamlessly. Skilled data practitioners are required to verify and validate such processes to enable machine learning towards a knowledge-based economy. According to one research, this will require "that citizens are equipped with analytical skills and other key abilities that are demanded by the private sector and are needed to function in a globalized market" [25], and hence a substantial reassessment, diversification, and upgrade of the quality and availability of Saudi education and research.

The importance of such skills is tied to the nuances associated with complex data. Complex data require proper presentation and representation that is intuitive and dynamic. Not an easy feat given that data are often contextual, originate from different sources, and more often than not, unstructured. Combining datasets can and often

[2] Visit www.linkeddata.org and www.w3.org/standards/semanticweb/ for more information, and consult Franklin, Stam & Clayton (2009) and Ruiz-Calleja et al. (2012).

do result in new datasets, unique and, arguably, independent of its provenance due to its unpredictable structure [29]. Most complex datasets are volatile and useful within a timeframe and can cause chaotic behaviour when not managed properly and sustainably. Because of this, tools and human capabilities surrounding data management must evolve to keep up with this complex growth. This includes emergent techniques in computing research, data mining, and visual analytics [29].

Research shows that Saudi Arabia still has a long way towards realizing such a labour force. Efforts are being made towards modernizing the Saudi educational system, with special emphasis on higher education and entrepreneurship to meet the demands of this job market [25]. This is especially true in the private sector, which falls short in contrast to the public sector. According to Al-Naimi [25], "the large population, together with the underdeveloped Saudi economy, has resulted in falling GDP in Saudi Arabia, even though it is one of the largest exporters of oil. The majority of the population are currently equipped with a traditional education, which has led to problems such as high youth unemployment, a concentration of jobs offered in the public sector, and an increase in rates of poverty." Youth unemployment is forecasted to increase, in light of automation, especially among females, and despite empowerment efforts. In one research [30], automation accounts for half of labour share decline posing another threat to the growth of human capabilities in Saudi Arabia and the lauded benefits of automation—given that most technologies are transferred or imported rather than sourced locally.

4. Successful ICT applications in the Kingdom

4.1 On the economic impact of the pandemic

There is no doubt that COVID19 has had an impact on the industrial sector in Saudi Arabia, on its economy, as well as on the international economy. There are three dimensions that reflect the ramification of the pandemic on Saudi industry [31]: (1) supply chain, (2) global demand, and (3) oil market prices. For the first, supply chains across the Kingdom witnessed a decline in production of imported goods, leading to higher input prices that prompted a need for new sources of supply. Global demand also suffered a decline that led to a decrease in Kingdom exports.

According to the Saudi General Authority for Statistics (GASTAT), the "total commodity exports decreased by 33.5% in 2020 compared to 2019" as a result of the 40.5% decrease in oil exports. Oil export decline caused a marked decline in oil prices by march 2020 at 35% compared to 2019 [31]. Likewise, the industrial sector labour market witnessed a massive decline by the end of 2020, where unemployment saw a loss of more than 5000 non-Saudi employees [31]. Even so, total unemployment rate among Saudi nationals reached 12.6% [31] in the last quarter of 2020, but was steadily improving by the end of the first quarter of 2021 at 11.7% (**Figure 5**) [32].

The success the Kingdom has achieved in managing the pandemic within its borders can be corelated to the successes of Vision 2030. According to the Bloomberg COVID Resilience Ranking [33], Saudi Arabia ranks second following the UAE, having risen 18 rungs to this position, taking into account 12 indicators. The two most significant are measured in terms of its positive response to the aftermath of the first 100 confirmed cases and successful nation-wide vaccination provision of 154.9 doses per 100 individuals. Its GDP is forecasted to grow at about 5.9% in 2022 [33]. Overall, managing the logistics in relation to the virus has been accomplished in several ways,

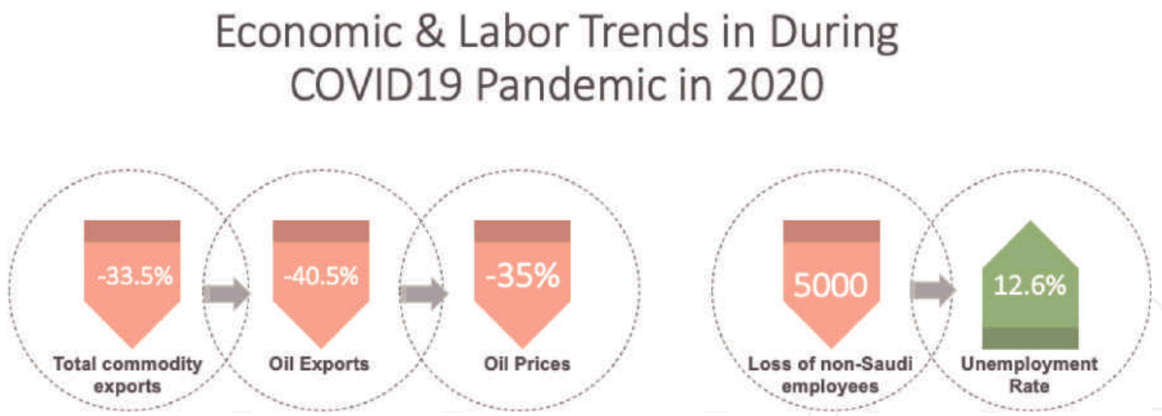

Figure 5.
Economic and labor market trends in the aftermath of COVID19. The figure summarizes the impact of the pandemic on the Saudi economy during 2020. Copyrights: Kinda Dahlan 2021.

critical to which has been the use of ICTs and the establishment of a unified national digital platform that is supported by the country's robust infrastructure.

When it comes to national economy, the government offered several e-facilitated support packages within the first and second quarter of 2020. Most packages were designed to provide liquidity for the needs of the private sector [31]. The value of packages in 2020 reached SR 70 billion Saudi Riyals (Approx. $ 18.6B USD). It entailed suspending tax payments, fees, and other dues to increase National Development Fund funding [31]. Likewise, the government also launched a program worth SR 670 million Saudi Riyals (Approx. $ +178M USD) that permitted loan repayment postponement.

Other measures included the provision of temporary electricity subsidies for the commercial, agricultural, and industrial sectors valued at nearly SR 1 billion Saudi Riyals (Approx. $ +266M USD). The Saudi government also authorized insurance-scheme packages for the private sector to counteract unemployment to promote retention of Saudi employees, whilst the Saudi Central Bank (SAMA) mandated banks to postpone loans repayment for Saudi employees for a period of three months without interest [31]. At the monetary level, SAMA launched a package worth SR 50 billion (Approx. $ 13.3B USD)—or nearly 2% of the GDP—to support the private sector. It provided financing to banks to facilitate the postponement of loan repayment and increase corporate lending [31].

Following the strategic Vision 2030, the government also implemented its localization policies to the industrial sector and supply chains as a response to the pandemic and other possible global shocks. This has resulted in a positive rise in local demand in certain sectors such as in the health supply industry (e.g., masks, sanitizers). Despite the opportunities, some industries were negatively impacted due to a high dependency on imported goods and global demand [31].

4.2 On the use of ICTs during the pandemic

During the COVID19 pandemic, which roughly began with the announcement of a nation-wide lockdown in March 2020, Saudi Arabia forged governmental policies and regulations to counter the spread of the virus by leveraging on ICTs and facilitating mass-public-health services.

Of note is the integrated unified national platform GOV.SA [34], which is in fulfilment of the digital aspirations of Vision 2030. This platform offers more 2500 government services, with more than 130 applications for 70 government agencies [35]. This unified digital platform offers an omni-channel user experience and can be accessed through a variety of central applications centralized around *Absher* [36], which provides government services to individuals, businesses, and government entities online. During the pandemic, two new apps were developed: *Tawakkalna*[3], a Saudi Data and Artificial Intelligence Authority (SDAIA) application that issues mobility permits for both government and private sector employees during curfew [37], and *Sehhaty*, a Ministry of Health application that facilitates access to accurate health information and the latest COVID19-related services [38].

Tawakkalna's 28 services are integrated with the public health awareness campaign "Cautiously We Return[4]". The remaining 15 are activitated during public lockdown. Tawakkalna also relies on near-real time social network data that can help detect possible contagion hot zones, alerting users and public officials of possible outspread. This has helped curb the *Delta* strain and limit the *Omicron* strain tremendously in the aftermath of the global pandemic. Both applications were developed and linked to the national platform GOV.SA. Other apps were also developed to provide national and international services such as *Eatamarna*, to facilitate Hajj and Umrah logistics and services.

In 2021, the apps, given the intricacies of the unified platform, were integrated such that users are able to access services from within these key applications, including nationally-sponsored entertainment ticketing services, traffic violations, and civil services. This was precedented by pandemic precautions that necessitated a means to organize mass-polymerase chain reaction (PCR) tests and vaccinations. These services are enabled due to structured citizen and resident data that has been captured and designed relationally to promote seamless logistics across the Kingdom. Other tangible benefits included the government's ability to support small and medium businesses (SMEs) in establishing their online presence during this time, postponing loan repayments, and developing new policies and regulations, along with multiple logistics processes that bolstered the existing infrastructure in support efforts for social distancing.

5. Discussion

5.1 Enabling Industry 4.0 in Saudi Arabia

Research shows that the ICT sector in Saudi Arabia will grow by 50% and the level of this sector's "Saudization"—or the promotion of Saudi national employment to alleviate heavy dependency on foreign workers—will increase to 50% by 2023 [39]. The Saudi government aims to transform the Kingdom into one of the world's leading countries in the field of ICTs "by building a digital economy based on the principles of the fourth industrial revolution and digital society management" [39]. The fourth industrial revolution, or Industry 4.0, is a paradigm shift [40]. This shift "requires the participation and commitment of different stakeholder groups [so that] industry can completely redesign supply chains, aiming at resource efficiency and circularity" [40].

[3] For more on Tawakkalna visit: https://ta.sdaia.gov.sa/en/index.

[4] Visit https://ta.sdaia.gov.sa/en/index to learn more about the awareness campaign.

Industry 4.0 is characterized by a set of enabling technologies that aggregate through the Internet and, as mentioned previously, Industry 5.0 complements 4.0 by centralizing innovation and sustainability. This trend is widely adopted as seen in the growing investment and rise in industrial engineering in the Kingdom [41]. If implemented properly, Industry 4.0 can produce real-time information on the locations and state of people and equipment involved in a process (IoT), it can provide measurement of connections and interactions (Big Data), and can produce predictive diagnostics and forecasts of system dynamics (ML and predictive analytics). To reach this state, data must first be converted into value. The popularized, almost cliched, *4 Vs of Big Data* hold true here when it comes to measuring the value of data: *volume* (the amount of data), *velocity* (the flow of data), *variety* (the type and characteristics of data), and *veracity* (the validity and reliability of data).

Lessons learned and research in data management suggests integrating policy, sharing practices and data characteristics into data architecture [42]. Key to these endeavours are mechanisms that verify the validity and reliability of the data stream because produced data and the way in which they are structured change from one use case to the other. Understanding when data are duplicated or missing is critical to the successful implementation of regulations that can transfer data into currency in a reusable and sustainable manner that supports innovation and market competition. Providing context, provenance, and other metadata helps mitigate unanticipated anomalies in data models.

It is important to note that the relationship between information technology (IT) infrastructure and data science is based on the utilization of datasets. Where one builds the infrastructure in the form of systems and platforms (IT), the other trades in its currency (data science)—namely data. For IT, the main role is to create platforms, storage and backup solutions, sustainability plans, and other mechanisms for organizing and maintaining data. For data scientists, the focus is to utilize available datasets in meaningful ways using machine learning and computation to aggregate, extract, clean, and validate data. In essence, data scientists *design* and *build* new processes for data extraction, modeling, and production. They use algorithms, prescriptive and predictive models, and custom analysis using prototypes to facilitate analysis. To develop a robust national Industry 4.0 infrastructure, both IT and data science expertise are needed to enhance manufacturing processes and to optimize the use of resources that bring about cost reduction and the elimination of wasted time. Saudi Arabia utilizes Industry 4.0 to optimize the use and manufacturing of non-oil-based resources, focusing on efficiency and upskilling. However, as we have delineated so far, concentration has been placed on securing ICTs and developing the IT components of this ecosystem rather than on data science and the development of human capabilities. This can be attributed to several reasons.

According to research by SAMA [43], there were several key points that were considered in creating a Saudi industrial development plan. First, it is essential to account for the differences between current and past structures, locally, regionally, and transnationally for any joint ventures to prosper. This is because of the unprecedented changes and developments in technology and shifting local and global demands (*volume* and *velocity*). Second, manufacturing has varying strategic definitions that are neither universal nor consistent—especially across borders—which necessitates an understanding of competitive advantage for each industry (*veracity* and *variety*). The application of internet technologies does not occur in equilibrium across business functions, industries, sectors, or even economies making a comparative analysis of digital transformation difficult to pinpoint.

For Saudi Arabia, there is an immediate planned adoption of Industry 4.0 technologies. This refers to Artificial Intelligence (AI), a subset of which is machine learning (ML), and the Internet of Things (IoT), which includes Linked Data and the linkage of devices and systems via the web. Other technologies include "robots, smart cities, the governance and future shaping of technology and data policy, automated mobility, unmanned aerial vehicles (UAVs), and the future of airspace" [16]. The biggest challenges facing Saudi Arabian industrial development and activity is the lack of demand—especially for SMEs—and the quality of natural resources, and shortage of skilled workers and expertise.

Further to this point, other challenges facing Saudi Arabia in the adoption of Industry 4.0 technologies and developing skills around it include: (1) "[l]ack of interest on the part of major industrial companies stemming from either a lack of awareness with respect to the existence of such technologies or reservations with regards to its effectiveness;" (2) "[l]ack of funding encountered by some firms to upgrade their production equipment, especially considering that equipment at the levels needed for Industry 4.0 are more expensive than conventional counterparts;" (3) a shortage in "human capital as qualified workers are needed to properly utilize these technologies," and finally (4) "[t]he strength of the Kingdom's communication structure and the information security infrastructure needed to utilize these technologies reliably and with enough protections" [44].

As mentioned earlier, these challenges can be counteracted through proper strategic planning and enabling supply-chain integration with machinery and databases. The adoption of new work models and implementation mechanisms are central to the realization of the Kingdom's Vision 2030 in that they necessitate a move away from relying on natural resources towards utilizing data as currency [45]. These challenges, and also opportunities and benefits, are summed up and illustrated in (**Figure 6**).

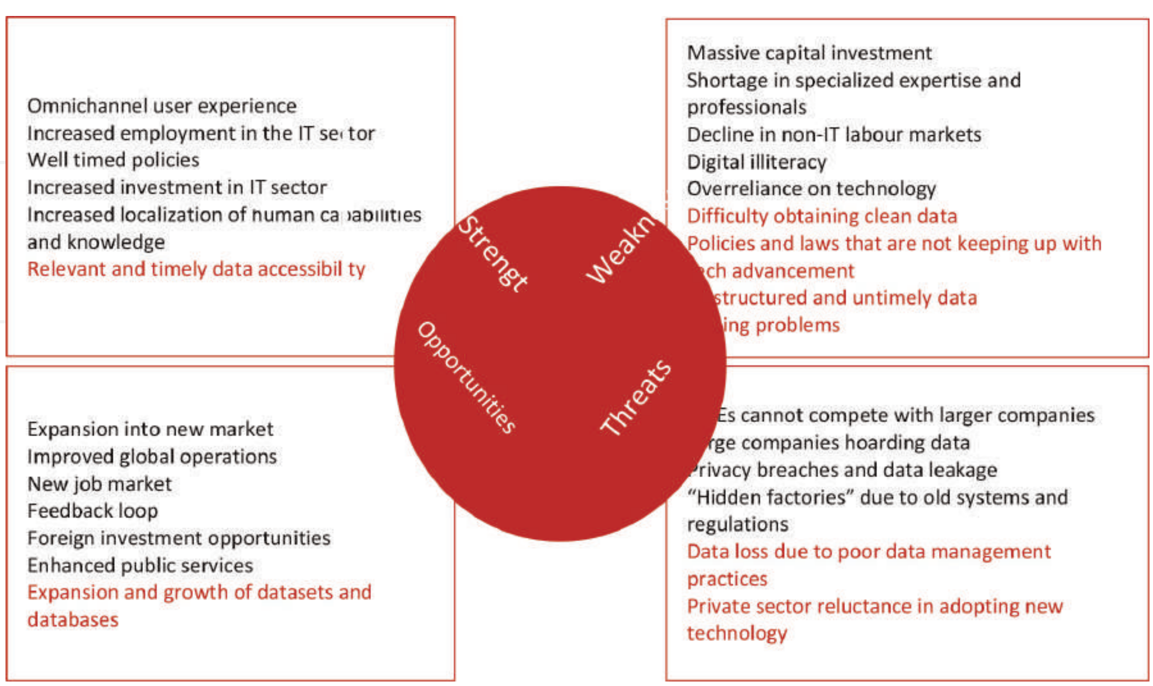

Figure 6.
The strengths and weaknesses of disruptive technologies in enabling Industry 4.0 in Saudi Arabia. The figure depicts the key advantages and disadvantages of utilizing ICTs and other web technologies. It also highlights the key issues facing data accessibility and management. Copyrights: Kinda Dahlan and Ali Megahed 2021.

Economic theory establishes that good economic data are a precondition to effective macroeconomic management: of GDP growth (oil and non-oil), of inflation rate, and of unemployment rates. This is particularly true in times of crisis for several reasons. First, due to macroeconomic policy timing, including monetary policies and fiscal policies, and second because of corrective policies that depend on well-timed availability of data. To be successful in offsetting the economic effects of crises, policy makers need to recognize these effects using real-time data. When there is a discontinuity between policy response and crisis impact, existing policies may not be effective enough to offset threats. Typically, this lag exists in the implementation of economic policies that are long and variable for monetary policies. However, we argue that the availability of clean and timely data can play a significant role in reducing this gap.

5.2 On the value of data and the limitations of data policies

For example, during the COVID19 pandemic, which began in December 2019, and taking into account the extensive time needed for the production of economic statistics to be collected (or published) by statistical authorities, regulatory responses (whether by government or businesses) were often late in interacting with accelerated changes for a given situation [42]. Untimely and messy data led to some poor decisions. This refers to incomplete, inaccurate, and insufficient data that impacted the manufacturing sector. To understand this further, it is important to visualize the degree of complexity in manufacturing data.

The Saudi manufacturing sector is composed of thousands upon thousands of units that belong to a wide spectrum of sectors as captured in the strategic vision. These sectors are interrelated through forward and backward links along the supply chain. These units are also interrelated with different nonmanufacturing sectors. Compounding this are interrelations with different cross-border manufacturing and nonmanufacturing sectors through international trade. We know that the COVID crisis caused many bottlenecks in the Saudi production processes, but also beyond it, due to supply chain disruptions as well as the accumulation of inventories as a result of shortage in product local and global demand.

As so, accessibility to robust and reliable datasets offer several benefits. First, they help identify bottleneck points and analysis of the possible different production paths. Second, they facilitate analysis of market supply and demand capacities in a way that enables predictions of market trends and potential action plans to minimize losses. Finally, reliable data helps government policy formulation in supporting sectors, subsectors, and/or units that are impacted most by a crisis. Economies usually keep track of sectorial interrelationships through what is known as input-output tables or Social Accounting Matrices (SAM). Such detailed data employ the use of advanced sophisticated mathematical models that accurately measure the impact of different economic shocks and hence the setting of appropriate policies.

Likewise, high quality effective data helps reduce uncertainty surrounding a country's economic conditions. This is a key interest for foreign investors, considering that one objective of Vision 2030 is precisely that: attracting foreign investment into the Kingdom. In practice, the quality of data housed in databases quickly degenerates over time, where estimates suggest that "2% of records in a customer file become obsolete in one month" [46]. The problem here is that data quickly becomes obsolete—a critical problem to data quality and value. Research shows that this not only has an impact on decision making, but that "dirty" redundant data cost "businesses 600 billion USD each year [... and that] stale data accounts for a large part of the losses" [46].

This highlights the importance of treating data as currency. Examining data as currency establishes the current values of entities within databases and datasets. This would not be a challenge if data values carried timestamp and provenance information. In reality, this metadata is often inconsistent, missing, or inaccurate. Likewise, the processing, and overprocessing, of data often results in incomplete, inaccurately-contextualized, and otherwise inadequate datasets. For Saudi Arabia, language is another challenge, keeping in mind that the language of the internet and web technologies is vastly English. The majority of data is either bilingual, or translated from Arabic into English for processing, increasing the odds of duplication, errors, and redundancy.

With low quality data in mind, and during the COVID crisis, there was a sharp decline in the flow of foreign direct investments (FDIs). According to the UN Conference on Trade and Development (UNCTAD) [47], global FDI flows in 2020 dropped by about 35% of what it was in 2019, reaching its lowest since 2005. This has had dire ramifications on economic development, and recovery from this situation required policymakers to position their countries as attractively as possible for FDIs.

When it comes to the manufacturing sector in Saudi Arabia at the time of the Corona virus outbreak, the government responded to the economic crisis, as many countries around the world have: by announcing stimulus packages to support its economy. Reiterating from earlier, at the monetary level, SAMA unveiled an economic stimulus package worth 2% of its GDP to support the private sector, especially small and medium enterprises (SMEs) [31]. At the fiscal level, the government allocated SR 70 billion Saudi Riyals (Approx. $ 18.6B USD) to help businesses through exemptions and postponement of government taxes, fees, and customs and to provide liquidity for private sector enterprises.

Both fiscal and monetary policies should be coordinated in such circumstances to boost support for impacted households and firms. To promote this, the availability of real-time valid and reliable data and, most importantly, forecasted data, is crucial to the successful management of the crises. This includes data on national public debt, its relation to GDP, and detailed sectorial data that enable policy makers to determine the most affected sectors. Under this category, there should be clear and up-to-date data on sectors that have high economic multipliers. These are the sectors that are deeply interrelated with other economic sectors through backward and forward links. Likewise, datasets of value should include sectors that depend heavily on imported raw material, sectors that are export-oriented, and sectors that are labour-intensive in order to evade severe impact on labour share and unemployment rates.

In turn, since the impact of policies ranges from short term to medium and long terms, relevant data should include solid predictions of economic variables that are based on reliable models. For example, although debt can push economic problems from the present to the future, doing so can aggravate the problem given that policies are often only as accurate as the input that delivered them initially are. It is important to observe here that the COVID crisis is related to real economy (supply and demand) not to financial problems; a distinction that highlights the lengthiness of recovery.

The policy taken by the Saudi government is ever so critical, but requires a serious consideration of policy timeframes to maximize its impact: is it a one-quarter shock? A two-quarter shock? Or perhaps more? The success of economic policies in offsetting the effects of a possible recession depend substantially on quick detection of the length of the recession. Such a policy should be consistent with the recessionary effects of the nature of the pandemic. This means that estimates are required for the starting and recovery time of the recession to distribute the policy tools accordingly. In this sense, access to raw data.

Well-structured, extensive, time-sensitive data is also an apparatus for post-policy measurements. In the case of the Corona crisis, access to adequate data facilitate the evaluation of stimulus packages effectiveness. This is done by measuring policy impact on real GDP and employment, whilst holding all other factors that affect real GDP and employment constant, as for example, other monetary policy tools, or business cycle changes. The mechanism behind such estimation is complex in nature and is affected by several factors that change supply and demand and, in effect, equilibrium GDP. In such a crisis, the success of policy is not as certain as regular times, leading to a wide variance in the estimation of the impact of stimulus packages.

Data used for such estimation are a significant factor in getting accurate results. For example, theoretically, the policy aims at shifting money-supply curve to the right, but the effect depends mainly on the behaviour of firms and households as a response to this shift. This response needs further examination using massive data (Big Data) extracted from surveys and other data sources that thoroughly address the behavioural motivations and decisions of households and businesses.

With this in mind, and given the limited data sources currently available for the Saudi economy, we recommend strengthening the quality of micro-level data, mainly through surveys at subsector or firm level, to expound the impacts of COVID19. This includes data beyond social data; on firm cost structures, consumer expenditures, and firm production and revenue. Similarly, improving data organization and structure, and enhancing national data lifecycle through proper database design, management, and archiving is elemental. This includes having more disaggregated data at the manufacturing level.

Data need to be collected at a higher frequency than currently is, and disseminated at regular intervals for timely analysis. To be able to have a forward-looking perspective, regular forecasts for many macroeconomic variables using solid and sophisticated modelling techniques such as advanced timeseries forecasting and regression models are necessary. Additionally, data should be tested frequently for accuracy, validity, and reliability as a means to improve quality. Likewise, accessibility is essential for conducting research studies that support policy makers.

As one research points out, "[a]mong the lessons learned are that data on the same variables are gathered by multiple means, that data exist in many states and in many places" and that "[d]ata sharing is embraced in principle but little sharing actually occurs, due to interrelated factors such as lack of demand, lack of standards, and concerns about […] ownership, data quality, and ethics" [42]. To assess data quality, and begin evaluating data as currency, Saudi Arabia must pay attention to data quality, accessibility, and provenance. This includes understanding the characteristics of data being generated; its frequency, flow, and reliability; for what certain and potential purpose(s); for whom, and with what access rights and regulations.

Further research needs to look into how data criteria vary in different contexts, what policy frameworks need to be applied, with what measures, controls and limitations. And while Saudi has made massive strides in utilizing ICTs in the public health and e-government sectors, we also recommend assessing the value of data, where several models exist to measure data as currency (e.g. [46]), and applying appropriate standards and practices towards maintenance and sustainability.

6. Conclusion

So far, we have described the Saudi national strategy, Vision 2030, in the context of utilizing technology and data to diversify national economy. We described the various localization efforts by government to strengthen the Saudi economy, improve human capabilities, and leverage on local content to reduce oil dependency. Likewise, we assessed Saudi digital readiness using several indices to examine e-government services, digital literacy, and to gage the realization of strategic objectives. We have also reviewed Saudi Arabia's response to the COVID19 crisis, detailing its utilization of ICTs, development of support packages, and regulation implementation. We conclude our chapter by addressing how our hypothesis levels against our findings, summarizing research results and implications, limitations, work advances, contribution to knowledge, and further avenues for research.

Reiterating from the introduction, there are two main hypothesis driving our research: 1) Data deluge brings substantial challenges in the timely collection and processing of massive amounts of information towards decision making, and that 2) the unprecedented production of information exceeds available human capabilities and the ability of authoritative bodies to create regulations and policies that can keep up with these transformations. Our findings reveal that there is a scarcity in research that looks into these concerns in Saudi Arabia. Our contribution to knowledge here is thus expanding on this body of work by providing insight into the successes and challenges facing the country as it journeys into its digital transformation and move towards realizing its strategic objectives. Our work has shown that there are limitations in educational initiatives targeting the development of human capabilities to meet the needs and aspirations of the national strategy. We have found that there are innovative efforts to address this gap within the Kingdom through various government-backed programs. However, our research also shows that traditional formal education remains the dominant national model in the Kingdom, limiting opportunities that can arise from the diversification of educational systems.

We also observed that while foreign investment is on the rise, knowledge transfer via these investments remains limited due to a heavy emphasis on ICT acquisition rather than on promoting knowledge transfer and exchange. Here we recommend further examination and research on the Saudization model to take advantage of foreign investment as a means for diversifying education, improving technical skill, and digital literacy.

Ostensibly, Saudi Arabia is a developing country that seeks to increase its potential economic growth through a number of policies and programs that include, among others, leveraging on digitization, capturing the value of data availability, ICTs, foreign investment, and industrialization. Economic growth studies suggest that capital, as an important input in the production function, could be classified into two categories: ICT capital and non-ICT capital. We have focused on the first whereby ICT capital includes spending on information, computing, and technology. Economic growth theories further reveal how this type of capital spending have been a crucial key driver of growth realized in developed countries over the last decade. Hence, ICT investment share trends in GDP is a very important measure of economic growth potential.

As so, and in terms of accurate data availability and accessibility, we showed that one of the most important causes of economic failures in the market is lack of data. Be they in the form of government setting policies that address economic issues, businesses that seek to maximize profitability, research bodies that try to analyse different economic or social phenomenon, or even on an individual scale to optimize better-informed decision-making processes. In all cases, data are invaluable currency. Linking the two points above is thus ever so critical in the formulation of information policy in Saudi Arabia. The work done in this chapter confirms the strong relation between economic growth and data availability and accessibility, and highlights the importance of investment in human capital and digital literacy alongside ICT capital. Using the Saudi case, where there has been an ambitious plan to converge the nation with developed economies, digitization and availability of accurate data remain key assets in this process. We studied the challenges associated with government responses to the COVID19 crisis. This included how data played a major role in counteracting the pandemic and helping in the formulation of government corrective policies. Studies to quantify the relationship between quality and availability of data and achieving economic targets for developing countries that have long term vision plans is a field for further studies.

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Chapter

Yacht Digital Design: Technologies toward a Computational Morphology System

Arianna Bionda and Andrea Ratti

Abstract

The huge transformation fostered by the current industrial revolution is changing each side of our society. In the design field, the use of digital and connected technologies improves not only the representation but also the formal references and the creative process itself. The research investigates the role of the digitally enabled technologies in modifying the disciplinary approaches to yacht design, a particular field of industrial design in which engineering and design approaches are mixed and overlapped. Through case studies and forecasting workshops, the research proposes a journey toward a more digitally conscious and virtually collaborative environment, highlighting as the traditional process of the yacht design discipline is no more valid. The research results, presented in the form of three roadmaps, show as 4.0 digital technologies are deeply transforming not only the representation of a design project but also its formal references and tools. For this reason, the three possible shifts in the yacht design practices are highlighted—input data are moving from analogic to digital reframing the focus from the measuring to inferring, the use of parametric and generative tools is shifting the "digital doing" from drafting to logic, digital twins are modifying the approach to communication media toward more collaborative strategies.

Keywords: digital technologies, forecasting framework, yacht design, design practices, digital design

1. Introduction

The present paper presents the final results of a three years research process that explores the topic of the digitally enabled technologies of Industry 4.0 with the purpose of understanding its role in yacht manufacturing transformation and then introducing its challenges into the field of yacht design practices. The choice of focusing on this research topic does not derive from a recognized field of study—the Yachting 4.0 topic is almost absent in the literature review—but rather from an intuition about the need to foresight the role of the new digital technologies and new manufacturing models in the transformation of the yacht design sector to understand and guide the undergoing digital transformation.

Since 2011, when it was first conceptualized, Industry 4.0 has been at the center of increasing attention from organizations, governments, and the scientific community [1][1]. As described by Herman et al. [2], the fascination for Industry 4.0 is two-fold. First, for the first time, an industrial revolution is predicted a-priori, not observed ex-post providing opportunities for both researchers and companies to shape the future actively. Second, the economic impact of this industrial revolution encompasses the entire design system, on new business models, product-service systems, and human behaviors [3].

The yacht design sector seems not aware and influenced by the disrupting transformations of digital production technologies and the new manufacturing models. The discussion on new technology impacts on the yacht design discipline struggles in considering the transition to a digital representation and digital manufacturing as a paradigmatic change of practices. Besides the few applications of smart materials and virtual technologies on board, the research is often limited to listing opportunities and challenges and in terms of technological availability, without really asking the question of whether and how the yacht design process itself will have to change to drive the digital (r)evolution. Despite the central role of the design discipline in a yacht design project, in the literature, this field of study is generally explored with an engineering approach[2]. The yacht design process is overall described as an iterative trial-and-error procedure aiming at satisfying predefined requirements; a sequence of operation represented as a spiral involving incremental optimization from the yacht's requested capability to the final design evaluation [5].

In this research, a reflection on novel yacht design practices driven by the digitally enabled technologies of Industry 4.0 is fostered. The explorations of future alternatives pointed at answering the two main research questions: *How could these technologies be better implemented in the yacht digital product-service ecosystem scenario? How do these scenarios modify the disciplinary approaches to the yacht design project and its practices?*

In the field of design, the Internet of Things, robotics, collaborative technologies, and intelligent products are profoundly transforming not only the representation of a design project but also the formal references, the input data, the communication strategy, and the design process itself. Digitally enabled technologies of Industry 4.0 revolutions—Industrial Internet of things (IIOT), Cloud Manufacturing, Additive Manufacturing (AM), Co-robots, Big Data Analytics, Simulation and system integration, Virtual and Augmented reality (VR/AR), and Advanced Human Machine Interfaces (AHMI)—are broadly considered the main drivers of the ongoing transformation. According to the main European Industrial plan,[3] the digital technologies could be divided into four families—connecting (IIoT and Cloud Manufacturing), manufacturing (AM and Co-robots), intelligence (Big Data Analysis and Simulation and System Integration), and digitalizing (VR/AR and AHMI). Furthermore, they come together with the six 4.0 Design principles [2, 6]—virtualization, self-configuration, real-time capability, service

[1] A bibliometric study identified an exponential growth in the number of publications per year on the topic, from only three papers in 2012 to more than 500 in 2015, and roughly 5,800 articles in 2018 [1].

[2] The large quantity of scientific articles is focused on naval architecture (the study of resistance to the movement of the hull), aero-dynamics (efficiency of the appendages and sails), structural engineering, construction, and material technology [4].

[3] Industrie 4.0 (Germany), Piano Nazionale Impresa 4.0 (Italy), Danish MADE, Made in Sweden 2030, Industrie du Future (France), Digital revolution in Industry (The Netherlands).

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orientation, decentralization, and flexibility—to strengthen the relationship between product-service systems and the manufacturing process.

The literature highlights two behaves of design principles (consciousness and interoperability) and two different levels of integration in the manufacturing and design processes as schematized here in a graphical representation. As shown in **Figure 1**, the principles make possible the development of Industry 4.0 at two levels of integration—a horizontal level—peer-to-peer and over the business value networks—and a vertical level through the manufacturing system, value chain, and customer services. Horizontal integration refers to the integration of the systems for and across the various product, production, or business planning processes. In other words, horizontal integration is about digitization across the whole value chain, whereby data exchanges and connected information systems are centralized managed. Whereas horizontal integration is about systems and flows in the value chain and the various processes happening across it, vertical integration has a hierarchical level component. These hierarchical levels are, respectively, the field level (interfacing with the production process via sensors and actuators), the control level (regulation of both machines and systems), the process line-level (that needs to be monitored and controlled), the operations level (production planning, quality management and so forth), and the enterprise planning level (order management and processing, the overall production planning, etc.). In this integration, a digital execution platform plays a central role in transforming the manufacturing headquarter into a hub of information and connectivity [4].

Trying to connect the digitally enabled technologies of Industry 4.0 and the six 4.0 Design principles, the authors presented in 2020 a radar diagram analysis, based on case studies, that resulted in a clear understanding of the technology strategic strengths in relation to their vertical and horizontal integration in the yachting industry digital framework (for methodological approach see Bionda [7]).

As shown in **Figure 2** "4.0 Design principles—digital technologies radar diagrams", AM and co-robot are employed in the horizontal integration in

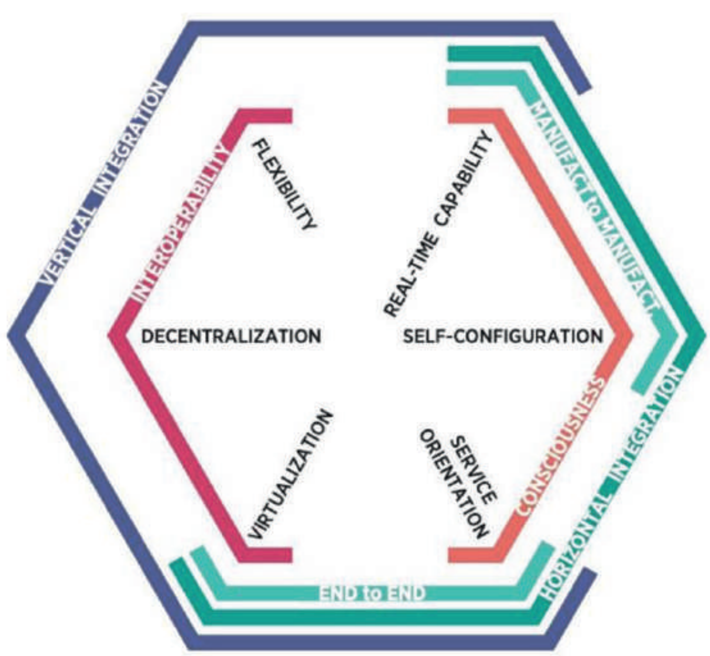

Figure 1.
Graphical interpretation of the design principles according to the different dimensions of digital integration.

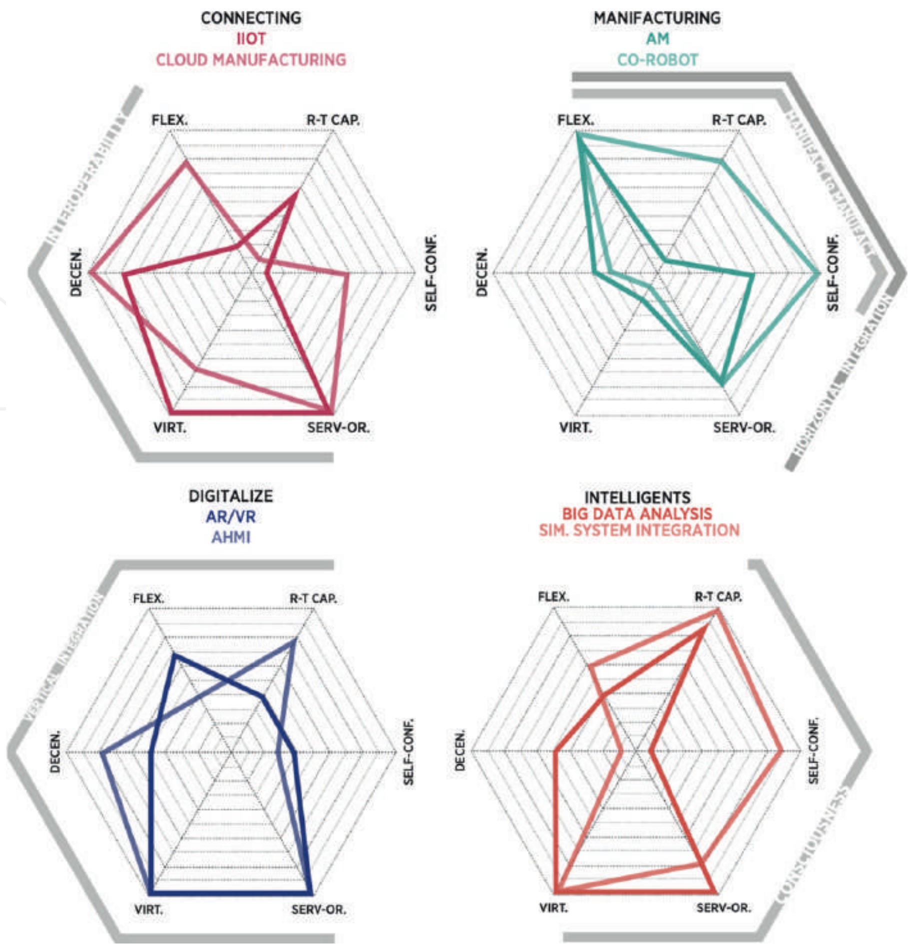

Figure 2.
4.0 Design principles—digital technologies radar diagrams.

manufacturing processes (manufacturing to manufacturing or design studio to manufacturing) with the main characteristics of enabling a more flexible production and, therefore, higher customization. The 4.0 technologies of the connecting family allow interoperability, the ability of a system to exchange and make use of information [6], and are applied in vertical integration processes. Close to the manufacturing family are the technologies big data and simulation and system integration allowing awareness of and responsive actions. These technologies share with IoT a high level in virtualization and service orientation and are able to respond in real-time for horizontal integration of manufacturing and design processes. Looking at the radar chart, the two families connecting and intelligence have complementary behaviors. At last, as the technologies of the digitalize group are mostly digital and virtual communication media, they could be implemented in vertical integration processes, not only at the two extremity of costumer journey sections—communication user-company and communication product-company—but also in each phase of design and manufacturing processes. The digitalized family technologies rely, furthermore, on the design principles of flexibility (i.e., higher customization) and real-time capability, collecting data, analyzing it, and making decisions straight away according to the new findings.

The enabling technologies of the fourth industrial revolution have overlapping areas of application and their implementation is based on digital design and simulation, highly automated manufacturing processes, production data management, and networking. The two main characteristics that describe the evolving system of digital

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manufacturing-plus-design are "information-driven"—referring to the consciousness principles—and "cyber-physical" with the connection of digital and real word and the ability of a system to exchange and make use of information through and across the value chain (interoperability).

The information-driven system is triggered by IoT and the idea of tagging and tracking "things" with low-cost sensor technologies. In this context, some authors also refer to the Internet of Services, which is based on the idea that services are becoming easily available through web technologies, allowing companies and private users to combine, create, and offer new kinds of value-added services [8]. On the other hand, cyber-physical systems can be defined as "a new generation of systems that integrate physical assets and computational capabilities and are able to interact with humans" [9]. In general, it consists of two main functional components—(1) the advanced connectivity that ensures real-time data acquisition from the physical world and information feedback from cyberspace; and (2) intelligent data management, analytics, and computational capability that constructs cyberspace [10].

Connecting the information-driven capacity with the cyber-physical system, the Industry 4.0 scenario will result in an increased capability of self-organization of manufacturing and other systems, which requires their digital modeling (i.e., virtual factory) and the use of advanced artificial intelligence for process control. As argued by Rodič [11], in this panorama, the product-manufacturing-service system has a unique digital representation, called Digital Twin, consisting of a digital shadow of the real product or manufacturing that alters its properties, condition, and behavior by means of models, information, and data.

It is clear as, in the contemporary panorama, a designer needs to face up design requirements strongly influenced by these advanced technological systems characterized by connected, computational, and open-sourced digital manufacturing. However, the discussion on Industry 4.0 impacts on design discipline is still immature, with few papers discussing the arguments since 2016, only [12].

In the next paragraph, the research methodological approach is presented together with methods and tools adopted. Then, the findings of the analysis of case studies are depicted and discussed as key drivers in the Yachting 4.0 forecasting framework. At last, the research results are collected in three scenarios and three roadmaps toward a yachting computational morphology system. The implications on yacht design processes of these roadmaps were then analyzed in the final paragraph of the chapter, showing the possible future shifting in the design practices on data input, design process and tools, and communication media.

2. The methodological approach: design for the future

If future scenarios and challenges cannot be predicted with an unquestionable level of uncertainty, they can be foresighted and understood to inform present acting. Due to the freshness and the "unexplored complexity" [13] of the Industry 4.0 topic and the lack of reference in literature, strategic thinking to explore alternative futures—Future Studies [14]—is prioritized. The beginning of all industrial revolutions took place in the industry and caused a massive change in society. The current industrial revolution is the opposite. The beginning of the transformation process is not driven directly by the industry itself [15] but is triggered by a hyper-connected society. For the first time in history, the industrial revolution is predicted, providing opportunities to shape the future actively.

For this reason, the methodological framework of the research is placed in the broader area between the Discipline of Anticipation [16] and Design, aiming to push the boundaries of yacht design practices. Furthermore, this context of investigation compels the research to continuously shift from field exploration and interpretation (surveys and case studies) and forecasting activity (participatory scenario-building workshop), opening up to several tangents or critical matters that position the study at a conceptual level to be verified with on-site practices.

Even though there are no data about the future, companies, designers, and policymakers currently use many strategies, methods, and tools to gather data for future investigation. Among them, the present study refers to the six-ing steps of activities depicted by Hines and Bishop in the book *Thinking About the Future, Guidelines for Strategic Foresight* [17] to answer the research questions. These steps were identified by the Association of Professional Futurists' Development Team as fundamental for a comprehensive foresight strategy. The six activities—Framing, Scanning, Forecasting, Visioning, Planning, and Acting—aimed at getting a systemic understanding of expected, alternative, and preferable changes in introducing the digitally enabled technologies of industry 4.0 in yacht design and construction practices. The concept of "system" implies that drivers of changes affect the behaviors in a network of interaction and feedback loops between input and outcomes. With this perspective, the present study, while aiming at investigating the changes in yacht design processes and tools, includes the broader sector of the yacht industry at the core of strategic forecasting research. The whole system embraces the design and production process as well as the user interaction, that is, sailing and maintenance stages.

The research strategy mirrors the six -ing steps of strategic forecasting, dividing the activities into likewise steps to drive the study from the initial literature review to the future study agenda, as following described.

The phases *Framing* and *Scanning* aimed at building a robust forecasting framework through desk research and case studies highlighting drivers in the digital yacht ecosystem, challenges, and uncertainties. The identification of the good practices for the case studies analysis was undertaken, thanks to the consultation with stakeholders—academics, naval and nautical shipyards, and suppliers, yacht designers, nautical industrial associations—while the case studies data sourcing was performed in two steps—primary source semi-structured observation (during the main nautical trades 2017–2019) and second data document review (online data). Then, the features of each case study were analyzed on the following four parameters—enabling technologies and sub-technologies for UX implementation, relevant 4.0 design principles, impact on YD process, and impact on the customer journey. The collective and parallel analysis of the multiple cases was executed, thanks to a card-sorting activity where the cases were gathered in overlapping clusters. This activity results in the Yachting 4.0 forecasting framework, described in detail in the next chapter.

Then, scenario-building workshop (*Forecasting* and *Visioning* phases) was selected as a forecasting method based on the nature of the uncertainty involved in the activity and referring to the Future Studies framework proposed by Courtney [18]. While case studies analysis was conducted with an expert mindset, the forecasting phase had a participatory mindset, involving stakeholders as co-researchers. To foster the participation and the interaction among stakeholders a proper set of activities and tools were designed following the Future Technology workshop method (FTW) [19], a method specifically suited to involve people with everyday knowledge or experience in a specific industrial process in an envisioning activity to design the interactions between current and future technology in a specific sector. The scenario-building workshop was divided into the four main FTW phases—a general introduction on purpose and forecasting framework, a structured brainstorming, a free envisioning session, and a scenario model building exploring the gap between current and future technology. The fourth step of the workshop involved, also, listing requirements and outlining critic aspects for future technology applications. This activity was the link with the next -ing phases—*Planning* and *Acting*—where a retrospective analysis to ground the workshop results in an understanding of novel yacht design approaches, processes, and tools driven by the Yachting 4.0 forecasting framework takes place.

The research results were then presented in the form of roadmaps, as the bridge between the forecast and the present situation [20], taking the scenarios developed in the participatory research at the destination. The method here adopted comes from Phaal et al. [21], where the roadmaps are conceived as the strategic plan that defines the digital scenarios connecting the different dimensions of the innovation strategy, the significant technologies and tools needed, and the plotted timeline.

3. Technology drivers for the digitalization of the yachting industry

As previously shown in the 4.0 design principles-technologies diagrams (**Figure 2**), the enabling technologies of the fourth industrial revolution have common behaviors and overlapping areas of applications that set the conditions on which to build a forecasting framework for the 4.0 development in the yachting sector. With the aim of further investigating that relation and revealing opportunities and trends for the scenario-building phase, a Case Studies analysis on digitally enabled technologies applied in the yachting industry was carried out. A card-sorting activity with an expert mindset was performed to grouped cases with the same behaviors without clustering them merely according to technologies adopted. After desk research, case studies were divided into three macro areas—design, manufacturing, and sailing. Some samples were placed across two groups representing a link between them. Looking at these links, two different groups were identified—the cases in which 4.0 technologies allow collaboration within multiple actors and the cases in which the virtualization and decentralization of communication media are predominate. The second stage of clustering involved the parallel investigation of the already labeled cluster to identify common grounds. The cases were, then, sub gathered according to the levels of consciousness in Industry 4.0 integration and to the influence on the disciplinary approach on the yacht design project in its processes and tools.

A graphic map to collect all the card-sorting clusters is here proposed to highlight the respecting relation between them (**Figure 3**). The map shows, at the central line, the depicted five levels of consciousness in Industry 4.0 integration—digital data gathering, simulation, optimization, system integration, and generative design. These five levels are put in relation to the two dimensions of communication and collaboration identified in the first step of cluster analysis. The resulting case studies groups are following labeled and described.

Digital data gathering: Projects integrating IoT and AHMI with the primary purpose of monitoring yacht assets. This group collects all the cases based on digital gateways, onboard electronic logs, and digital platforms for vessel system control and automation. Plus, it includes the environmental digital data analysis with the main purpose of gathering and analyzing field data to (in perspective) inform the design

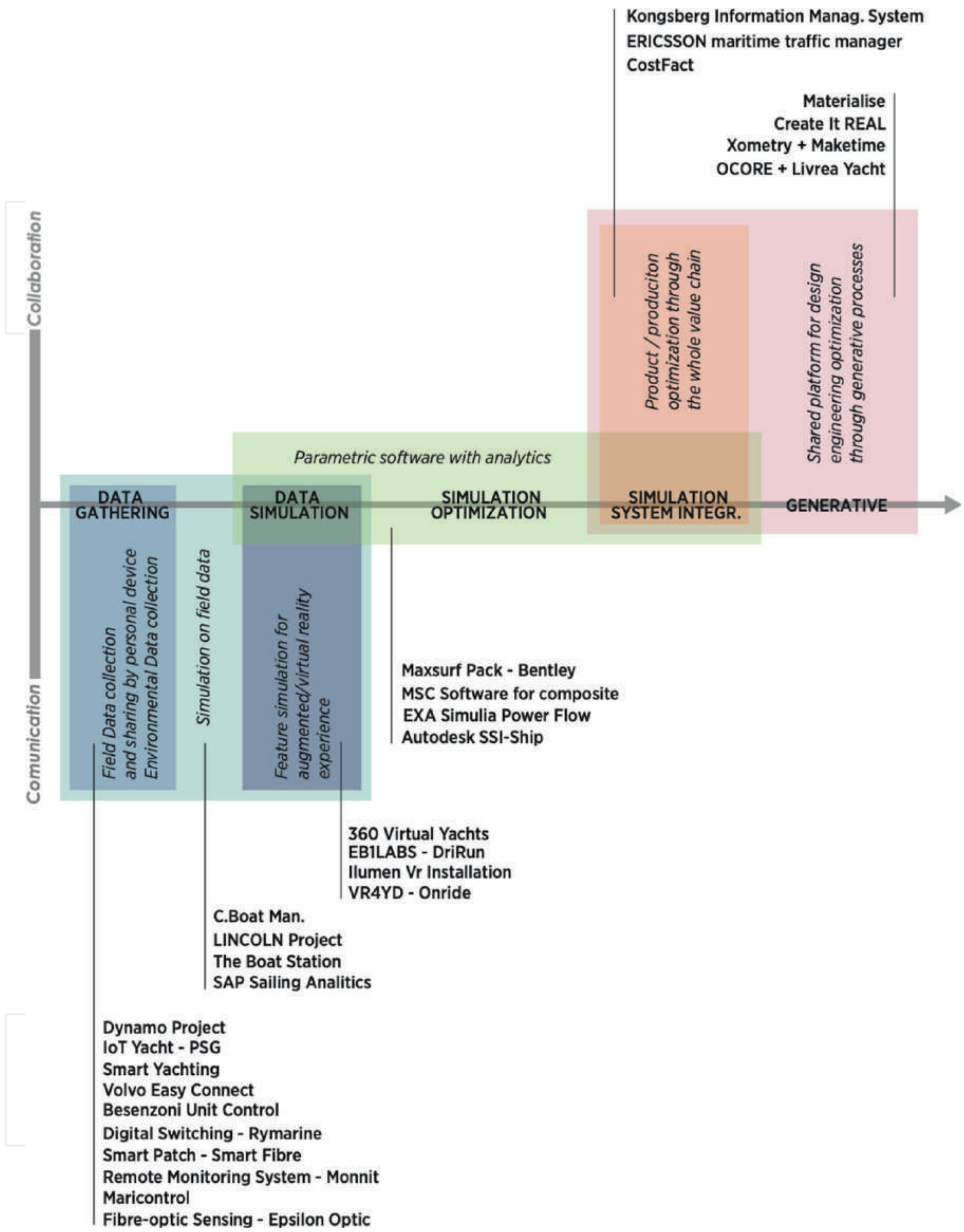

Figure 3.
Case studies map.

process. Vessel and marine environmental data gathering from IoT structures are mainly used in this cluster for maintenance purposes. Only one case experiments the possibility of confronting field data with design data.

Data simulation for communication purposes: Projects not informed (or partially informed) by field data integrating big data, simulation, VR, and AHMI. The main examples are a virtual reality in marketing strategic communication and virtual sailing testers.

Simulation analysis and optimization: Projects not informed by field data in a not-integrated ecosystem. This group encompasses simulation software to predict real-world performance and tools for manufacturing process optimization.

Optimization through system integration: Projects with a collaborative nature aiming at the optimization of both product and process through the whole value chain. This group collects all the collaborative platforms developed for the marine and yachting industry to manage the design phases, the value chain, or the offshore and sailing operation.

Optimization through generative: Projects involving generative design tools to optimize and self-configuring product shape according to the manufacturing process. This cluster encompasses the collaborative platforms currently used for managing the manufacturing process with the aid of digital assisted tools as additive manufacturing and collaborative robots. These case studies have a collaborative nature aiming at self-configuring product shapes according to the manufacturing process by the use of generative design tools. A few cases, including cloud manufacturing as the key technology, are gathered in this group.

We can observe in the map, a clear separation between the two categories, which are communication and collaboration. Communication strategies are more implemented with low consciousness projects, while collaborative strategies lead projects with a higher level of systemic integration and self-configuring processes. The technologies adopted on the left side of the map refer to the design principles virtualization, service orientation, and decentralization. On the other hand, cases that implement the use of collaborative platforms for generative design do not make use of field data through the entire value chain, as well as the optimization processes. We can observe that the technology adopted here leads directly to flexibility, self-configuration, and real-time capability as design principles crossing the two areas of horizontal integration in manufacturing and design. In particular, new media of communication are emerging in the relation within companies and the yacht final user to allow (i) a more immersive experience, and (ii) faster and easier access to information through digital platforms and self-devices.

4. The Yachting 4.0 forecasting framework

To build the forecasting framework for the scenario-building phase, the results of case studies analysis are observed through the lens of the ecosystem approach for Industry 4.0 scenarios by PWC [22]. The PWC Industry 4.0 scenario framework identifies four steps in moving from a product-oriented to a platform-focused approach—(i) Core Product, the traditional base offering, which can be "digitized" by adding digital layers around it; (ii) Digital Augmentation, digital customer interfaces, visualization, touchpoints, and channels augment the experience and allow a variety of interaction models; (iii) Digital Service in which digitally enabled services are added to the physical core product providing an end-to-end solution to a broader customer need; and (iv) Digital ecosystem with interfaces to suppliers, partners, and customers, the product is embedded in an ecosystem for co-creation and additional value capture.

In the present study, the PWC Industry 4.0 scenario is expanded to include the manufacturing process in the systemic approach and the "after launch" stage. As we can observe in **Figure 4**, the scheme becomes a group of four concentric circles divided into four sectors by the vertical and the horizontal axes.

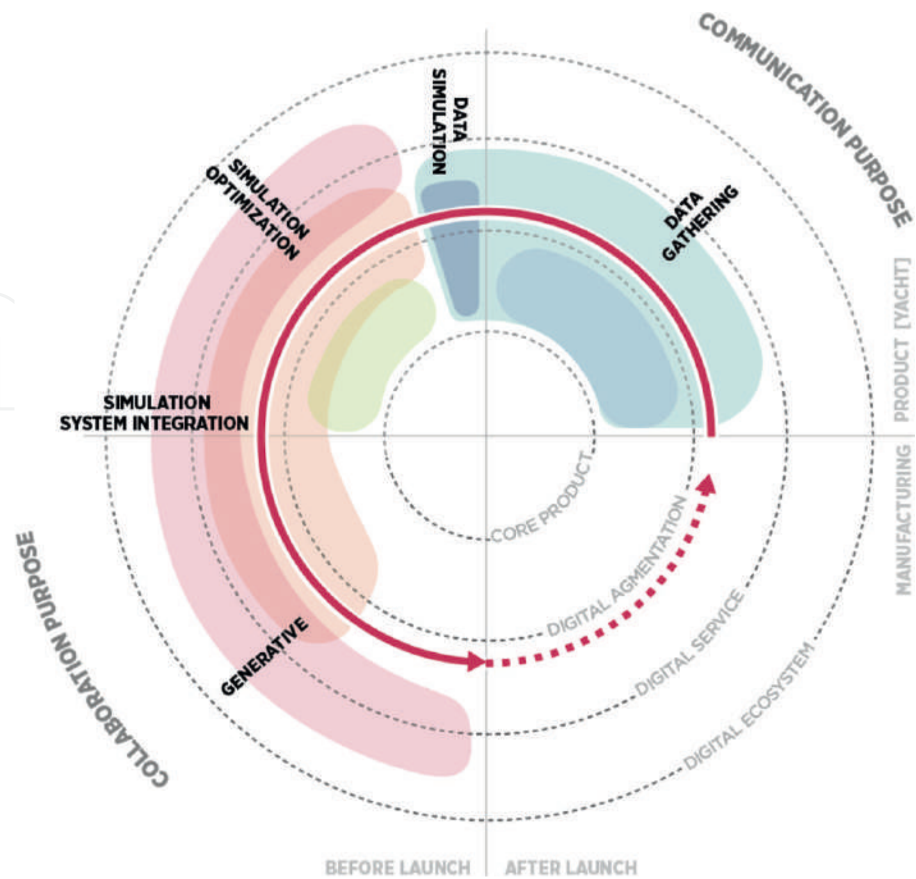

Figure 4.
Yachting 4.0 forecasting framework.

The horizontal axis separates the focus on product from the focus on production, while the vertical axis marks the temporal division between before launch and after launch phases. The four sectors of the circles result in design (focus on the product before launch), manufacturing (focus on production before launch), sailing (focus on the product before launch), and maintenance (focus on production after launch). The Yachting 4.0 forecasting framework is built by overlapping the groups of the Case studies map to the scenario framework scheme with the purpose of giving fundament in answering the first research question—How could these technologies be better implemented in the yacht digital product-service ecosystem scenario?

A clear barrier between the “before launch” and the “after launch” sections is observed. This evidence refers to the previously depicted separation between collaboration and communication. The digital data coming from field and user engagement are not yet employed in the design phase and maintenance stage. This results in a disconnection between the after launch and before launch phases at the expense of input data design quality and quantity.

On the design and manufacturing side, horizontal integration of digital data for simulation, optimization, and self-configuration (generative) process is arising. While communication strategies are more implemented with interoperability projects, collaborative strategies lead projects with a higher level of consciousness and of systemic horizontal integration. In these cases, the implementation in the use of collaborative platforms for optimization and generative design process does not make use of field data through the entire value chain. At last, the visual representation of the Yachting 4.0 forecasting framework shows a lack of experiences in the last circle, the digital ecosystem, and an insufficient connection between the four sectors of the graph. This fact is a further confirmation of the general immaturity of the yachting sector on the theme of Industry 4.0 and a need for systemic visions, leading the research activity into the scenario-building workshop.

5. Three scenarios for the yacht digital design

The workshop activity, conceived as a co-research phase, had three objectives—(i) discuss and validate the scenario framework; (ii) explore and build alternative scenarios on Yacht Design 4.0, outlining drivers and criticalities; and (iii) involving and making aware of the specific industrial community on digital technologies opportunities. To achieve the intended research objectives, the workshop involved experts in the yacht design field—yacht designers and draftsmen in the yard, shipyards project and production managers, yacht industrial association managers, and experts in digital transformation and policymakers. The workshop took the FTW scheme as a reference aiming at reaching an informed understanding of a grid of four boxes—everyday technology and activities (core product), an everyday activity supported by new technology (digital augmentation), a new activity supported by current technology (digital services), and new activities with new technologies (digital ecosystem). Moving inside the grid, the workshop partakers are guided in the scenario visioning activity.

The workshop was focused on yacht design practices, but a systemic view on the whole yachting sector was fostered. For this reason, even if the whole scenario-building workshop was divided into the four main phases described in the methodology, parallel and circular activities were performed in an iterative conversation among challenges and opportunities, especially in the free envisioning and scenario exploration phases. As a workshop result, three visions symbolized by the three Roadmaps were created.

The definition of the Yacht Design 4.0 Roadmaps was, in itself, a design matter. Sustained by all the qualitative data and knowledge, collected by case studies and by the co-design visioning activity, the roadmaps represent the synthesis of the collaborative activities, and the grounding of the workshop results in an understanding of novel yacht design approaches, processes, and tools driven by the Yachting 4.0 forecasting framework.

The multiple scenarios developed in the workshop were grouped up based on common ground identification looking at (i) the four steps of digitalization of the Yachting 4.0 forecasting framework; (ii) the insight coming from the workshop scenario exploration phase and shared by the workshop partakers; and (iii) the three cluster of yacht product and production, which are [23] top of the line, model-based, and semi-custom. The timeline for a roadmap toward a computational morphology system was defined according to the workshop results discussed with the partakers:

- current: digital augmentation, within five years;
- near future: digital services, within 10 years;
- and futures: digital ecosystem, from 10 to 20 years.

In the next sub-paragraphs, the three roadmaps are presented and depicted together with their implications on designer work and their critic aspects, as discussed with the scenario-building workshop partakers. The implications on yacht design processes were then analyzed on the primary levels already set in the previous research activity (case studies)—data input, design process and tools, and communication media.

5.1 Top of the line roadmap to digital product-service ecosystem

The top of the line cluster encompasses companies dealing with a high level of product customization and looking toward the larger segment of super- and mega-yachts. This type of boat is part of what is called luxury design, where the project is highly influenced by the specific culture and personality of the client [24], where the request for a craftmanship tailor-made product is continuously increasing, and the focus of the market is shifting on rare and personalized experiences [25]. The roadmap takes the peculiarity of this cluster into account, proposing a journey toward a digital product-service ecosystem in which personalized service and yacht components are designed on real data gathered in a digital experience platform.

Current: The first step is the digital augmentation of both the design project, that is, 3D model of the yacht, and the product, that is, the yacht itself. The yacht design modeling becomes parametric. The designer interacts with a digital structure that was generated by a mechanism according to a set of predefined relations between shapes and components. In this way, the first phase of preliminary concept design embeds the design engineering steps allowing rapid change of design dimension and structure in the project representation. On the other hand, sensors and remote-control networks are placed on-board, transforming the vessel into a connected object. The first level of services proposed is (i) the electronic log for sailing automated data recording, (ii) the gateway of the universal system, and (iii) the social media integration. The user experience data are recorded in a knowledge management platform.

Near future: The second step is the connection of the knowledge management platform, featured with big data real-time analysis, to the design project. Knowledge management platform examines large and varied field data sets to unveil hidden patterns represented by formal, computer-interpretable rules. The design project makes use of the data resulting from the iterative process of data analysis and simulation to verify the yacht premises. Furthermore, the yacht 3D model becomes a non-living digital twin—a digital replica of all the physical and IoT assets of the vessel, allowing direct communication with both the production site and the whole supply chain. Virtual/augmented reality and AHMI tools could be used as communication media for a preliminary customer immersive experience. For what concern novel digital services, the use of big data analysis allows the development of on-board personalized service including optimized and automated routing according to sailing analytics, to environmental and forecast data, maintenance and marina service feed by real-time field data, and legal insurance services.

Future: The digital product-service ecosystem encompasses the physical and the virtual world, and data are transmitted seamlessly (and in two ways) between the yacht and the living digital twin. The knowledge management platform examines not only the field data sets but also the design project information, allowing interoperability and vertical system integration between yacht components. At the same time, the parametric digital twin is conceived as a living project providing insight on both the elements and the dynamics of how digital devices operate and live throughout the yacht life cycle. The yearly maintenance or refitting stage benefits from the field data gathering and analysis of the digital experience platform, allowing a yacht optimization on real customer needs.

Implication on yacht design process and tools: In this scenario, the yacht design processes maintain its character of an iterative cycle of refinement steps. Due to the use of a parametric design tool,[4] the sequence of steps of simulation and optimization are integrated into a unique analytical process on geometrical models.

In this contest, the living digital twin is managed by parametric design technologies and optimized by the result of the digital experience platform analysis. Moreover, the design platform could allow multiple evaluative analyses and support the collaboration among the different design and engineering teams involved in the yacht design process. At last, the living digital twin embedded in the digital experience platform could be visualized through virtual reality digital devices both for augmented customer experience and manufacturing/maintenance purposes. The representation highlights not only the yacht feature and the control gateways but also the information on how the yacht, the systems, and the components operate throughout the whole life cycle.

Critic aspects: The scenario shares with the broader Industry 4.0 development the challenge in data and privacy protection. Even if the ethical challenges created by mass data gathering through online interactions are scientifically reported [27], there is not a clear policy ethical framework on digital technologies due to the rapid and disruptive changes in the information technology environment. On the other hand, maritime sector suffers from cybersecurity as well. According to the EU report on cyber security challenges in the maritime sector [28] and the findings of the collaborative scenario-building workshop, maritime cybersecurity awareness is currently low to nonexistent.

5.2 Semi-custom model-based roadmap to generative-integrated ecosystem

The second group represents the companies with a model-based production with a high level of flexibility and customization of the core product, of digital integration in design and production processes, and experience in 4.0 enabling technologies. The roadmap to a generative-integrated ecosystem takes the current advancement of the cluster into account, proposing a journey in which the virtual data coming from user experience and field measurements could inform the design phase in generative processes for higher optimization and personalization in project development. The roadmap from optimization to generative consists of three steps, which are as follows:

Current: To support the present design process (from concept to design engineering), a knowledge management platform is placed across the sailing and the production stages. Data coming from the digital augmentation of the yacht and the vessel production tools are recorded and analyzed. The process data outputs are formal, computer-interpretable rules that are considered in the parametric yacht design modeling. Knowledge-based methods have been intensively studied and applied in other transportation industrial sectors, such as maritime; however, it has not been studied or adopted in the yachting industry, dominated by low volume production and small or medium-sized companies, so far. Despite that, the large amount of already formalized engineering knowledge in codes and regulations could be implemented in the yacht design as well.

[4] The relations between the project dimensions are no more directly drafted on a digital continuum space (as in a cad direct modeling tool) but are dependent upon various parameters. This process is generally described as predictive models, as opposed to direct modeling, in which the descriptive modeling process brings together with manufacturing logic and material proprieties [26].

Near future: The second phase represents the knowledge integration into the yacht digital twin. The refinement optimization steps are directly managed by the digital replica of all the physical and IoT assets of the yacht. The integration in a unified platform allows direct communication with both the production site and the whole supply chain. The communication media becomes a digital interface on personal devices, and production work teams could interact with the digital replica sending feedback to the knowledge management tool. Virtual reality and augmented reality could be used to verify the features and the assembly operation of onboard optimized components.

Future: A generative design tool is integrated into the knowledge management platform to transform the data coming from user experience and field measurements into alternative shapes. This process allows the generation of different solutions by changing the parameters of design constraints (from knowledge management platform) and design requirements (from direct design modeling). Consequently, the quantitative analysis of computational techniques based on the finite-element method is translated into qualitative alternatives of complexity. The use of parametric and generative design tools is driven by the possibility of applying advanced manufacturing processes to yacht production. In particular, additive manufacturing and cloud manufacturing could represent a turning point in the customizability of yacht components.

Implication on yacht design process and tools: In the generative-integrated ecosystem, the current parametric design process is shifting toward a computational process model of digital design under the impact of a new generation of associative algorithms. The linked and iterative cycles of design, analysis, simulation, and optimization of the yacht design spiral are no more valid in describing the new paradigm of the yacht design process. The two platforms of knowledge-generative design and integrated management have unified the process of simulation, evaluation, and fabrication within designer-scripted morphogenesis processes. Furthermore, the integration of the 4.0 enabling technology of additive manufacturing and collaborative robotics in the roadmap led to including the "making level" in the design process.

Critic aspects: Besides the previously mentioned ethical issues on data confidence and privacy and cybersecurity, a discussion on the shifting role of designers emerged. Although the parametric approach has increased the interoperability of systems and the flexibility among geometry relations, the exploration of yacht design alternatives is still limited by the manual operation of designers in varying individual parameters. Whereas, what a generative approach does is asking artificial intelligence to explore the design space semi-autonomously, revealing options that would otherwise be hidden. The designer role is shifting at the beginning and final stage of the process interacting with the generative structures of the yacht model, defining the project requirements and the grammar of shapes, and finally evaluating the generative results. New digital skills are requested for designers and a new way of thinking. These challenges are also arising in academic research around the concept of digital design thinking [26].

5.3 Model-based roadmap to co-modular digital ecosystem

The third cluster encompasses the companies that have a lower value in customization and an engineered production process. The cluster is mainly represented by shipyards dealing with low series and mass assembly core products even if a request for higher personalization is rising in the market, which are claiming for more flexible and integrated process in both the design and the production of yachts. Moving from mass production to mass personalization is challenging the worldwide industry from the early 90s and is extensively discussed in theory and applications [29, 30]. However, the integrated use of the enabling technologies of Industry 4.0 seems to offer a solution to the dilemma between the economies of scale and scope triggered by the concept of mass customization [31]. In this context, the model-based roadmap envisions a journey toward an integrated-modular digital ecosystem, where the yacht product, design, and production processes consist of integrated (design-production-product) subsystems with little interdependencies serving as modules links.

Current: As for the previous roadmaps, the first step in digitalization is the digital augmentation of the yacht design project and the model-based yacht. The parametric design tool for yacht 3D modeling is directly connected to a virtual configurator, able to manipulate the set of parameters according to the designer's work. In this phase, the customers interact through a personal smart device (AHMI) with a digital structure generated to link furniture finishing and components features. A knowledge management platform received and store the data coming from the onboard IoT system as component sensors and universal system gateways. The service offered to the final user is the ones described in the roadmap to the digital product-service ecosystem.

Near future: A yacht digital twin is optimized with the data coming from the onboard IoT systems. This digital replica of all the physical and IoT assets of the vessel represents the link between the production site and the customer virtual configurator. The yacht project is conceived as a flexible assembly of different modules regulated by interdependences in a virtual logic structure. In this vision, the boat could be highly customizable. The effectiveness of the modular yacht concept is already proven by several commercial proposals and academic research [32, 33]. The customer virtual configurator is conceived as a co-creation guiding tool to build customized solutions based on predefined design variables and limits. The opportunity offered by VR/AR on smart devices and AHMI allows to virtual test the finished product and provide end-user with product support.

Future: An integrated and modular digital platform is placed at the core of the design process involving not only the yacht conceptualization and engineering through digital twin modeling tools but also the production and supply chain assets managing. Both the design and the production process are divided into interconnected and integrated subsystems. An interdependence logic structure manages the modules relation based on configuration variables and yacht design constraints. Furthermore, the subsystems are optimized by the analysis of the digital field data coming from the connected vessel (i.e., connected subsystems of different vessels) and the digital-based production tools, such as co-robots and additive manufacturing. Although introduced on modular yacht design products, the concept of modularity is now applied to many different areas of the production system, production planning, and optimization processes.

Implication on yacht design process and tools: A sequence of four steps divides the design process of the co-modular digital ecosystem scenario. (i) Definition of a pre-set of general condition and parameters mirroring the first cycle of the yacht design spiral aiming at setting the interdependence logic structure of yacht based on the configuration variables and the yacht design principle and constraints; (ii) Variants generation of subsystems according to market and trend research. This step involves, furthermore, the module links definition and the logic correlation between subsystems; (iii) Variant optimization by field data from product performances (sailing and user experience), from the production process, and supply chain management;

and (iv) Variant selection, final product visualization, and evaluation by customers through virtual reality. The collaborative design process here involves the customers in flexible customization. In this scenario, the design process is supported by a parametric tool involving the generation and management of digital representations of physical, functional, and production properties of subsystems and their logic/construction links.

Critic aspects: In addition to the previous scenario criticalities that remain constant even in this third vision, a generally low level of digital experiences in the yachting sector could represent a crucial aspect in the development of the roadmap. Furthermore, the small and (sometimes) family dimension of the nautical supply chain could be a barrier to digital integration. To bridge this gap, specific design competencies in parametric and integrated design are needed across the whole value chain at different hierarchical levels.

6. Computational strategies in digital yacht design

At last, this paragraph discusses the research results presented through the roadmaps, putting them in a broader conversation with the recent debate on parametric morphologies, computational design engineering, and digital design thinking. As shown by the roadmaps, the journey toward a computational morphology system affects not only the design practice with the use of novel design tools but also the input data, the design process, and the communication media between designers-customers and designers-manufacturing. The roadmaps highlight that the yacht design process is progressively moving away from the linked and iterative cycles of design, analysis, simulation, and optimization of the yacht design spiral. The novel approach seems reflecting the level of 4.0 consciousness previously described in the framework—simulation, optimization, and generative design (**Figure 5**). The Yachting 4.0 forecasting framework also suggests that the digitally enabled technologies are driving the yacht design process toward a more digitally conscious and virtually collaborative environment. Three different approaches to the yacht design process driven by digital and computational modeling tools are depicted and named—digital yacht design spiral, digital yacht module optimization cycle, and generative yacht design tangle.

At first, in the roadmap toward a digital product-service ecosystem, the yacht design process maintains its characteristic of an iterative cycle of refinement steps feed by real-time data. The Digital yacht design spiral (**Figure 6a**) represents the first level of the 4.0 consciousness: simulation. The data analysis and the design process are still being separated, and the manual operation of designers drives the optimization process in varying individual parameters. In this process, the use of parametric design tools allows interoperability between different design and engineering teams as well as a direct connection with the digital twin (conceived as the communication medium between stakeholders and digital assets). However, the exploration of yacht design alternatives is still directly connected with the capability of designers in interpreting customer requirements, setting production and material constraints, and understanding simulation results to appropriately vary the individual parameters of 3D models.

The second level of 4.0 consciousness in yacht design processes—optimization—is represented by the roadmaps to the co-modular digital ecosystem and the process "Digital yacht module optimization cycle" (**Figure 6b**). In this roadmap, the yacht

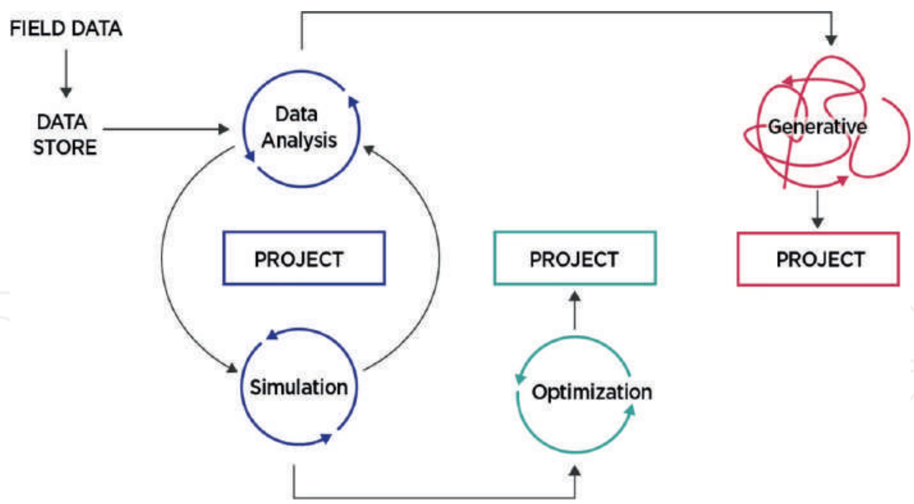

Figure 5.
Computational strategies in the Yacht design process.

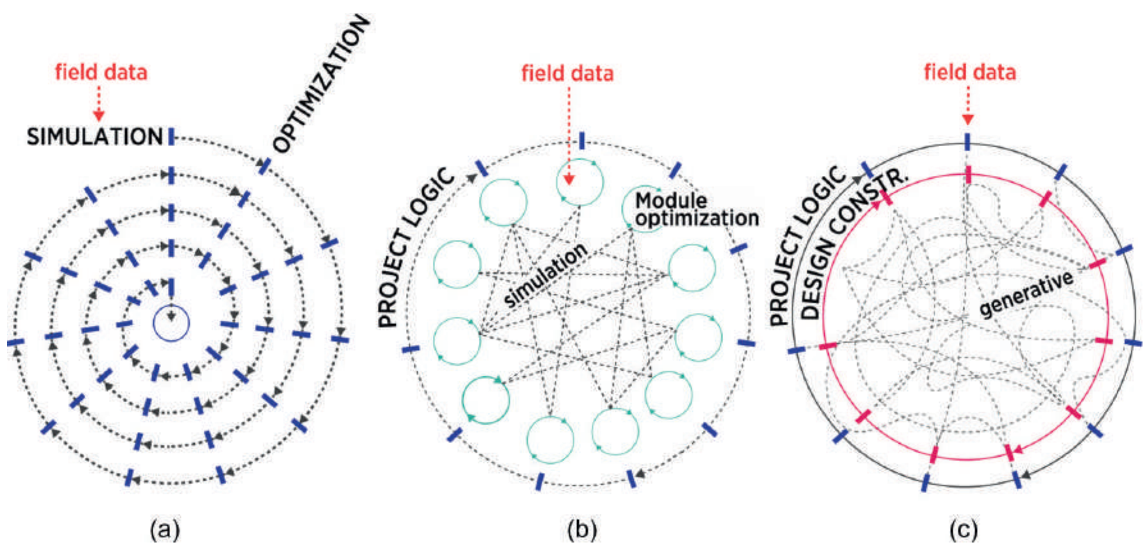

Figure 6.
Approaches to the yacht design process driven by digital and computational modeling tools: (a) Digital yacht design spiral; (b) Digital yacht module optimization cycle; and (c) Generative yacht design tangle.

design process is not entirely managed by the designer/team itself but is the result of a collaborative process of co-creation with customers. The sequence of refinement steps characteristic of the yacht design process is here moving from the entire product conceptualization to the design of the single subsystem. The exploration of yacht alternatives is directly managed by customers and mediated by a digital platform that embedded the logic of the project and the self-assembly optimization parameters. Working on the logic of vessel design, structure, and modules interconnection, the yacht design process is not opened to disrupting co-design results, even if novel assembly systems and unexpected results could be created by co-design interaction.

In the generative-integrated ecosystem, the current parametric design process is shifting toward a computational process model driven by associative algorithms, driving the reflection toward the Generative yacht design tangle (**Figure 6c**). Already experimented in a few yacht design cases and intensely explored in the literature review in the industrial design and architectural field, generative processes are disrupting the dichotomy between creative thinking and digital drafting. In the generative processes, the focus of artificial intelligence is not analyzing and simulating data but exploring alternatives and creating a solution. Within the different types of generative processes, a grammar-based approach emerged as the more suitable in the yacht design field. In this process, the designer interacts with the generative structures, their limits, and input, defining the grammar of shapes, and finally evaluates the generative results [34].

Contrarily from the previous two processes, here, the design results are multiple and interchangeable. The selection criteria of the proper design solution is still an open issue, not discussed in the present study, and weakly tackled in the literature review on the design engineering field. The research highlights three possible (future) shifts in yacht design practices.

Input data: Data are moving from analogic to digital and the opportunity to networking information distributed across many different sources shifts the focus of data input from measuring to inferred (i.e., big data analysis). Parallel to analogic data—marketing and customer insight, specific designer and engineering knowledge, and onboard experience—yacht designers could make use of a large quantity of direct data measured by sensors and smart devices. In the digital augmentation sphere, not only IoT design data are accessible everywhere, but information from many different devices can be combined in datasets. It is important to underline that digital data coming from production processes and intelligent vessels become the new oil for design empowering and customer involvement only if they can be fully understood within a qualitative context framework of previous analogic yacht design knowledge.

Design processes and tools: The use of parametric and generative design tools is shifting the "digital doing" from digital drafting to digital logic in which the digital focus is the creative process itself. In focusing on the design process, moving from direct modeling to parametric design and then, to generative yacht design, could fragment the dichotomy between the creative thinking and the digitally drafting of the vessel shapes. Here, artificial intelligence is asked to explore the design space semi-autonomously to disclose options based on predefined generative rules, relations, and principles. An alternative way is presented through the roadmaps and identifies the journey toward a modularized system of optimization. Even in this process, the digital focus is moved to the logic structure. While in the generative design process the "logic" refers mainly to the design principles and the grammars of shapes, in modular-computational processes, it has to do with the relation between elements and junction constraints. This focus on the reasoning level of the design process is highlighted in the purposes of generative and computational design processes [35]: "creating responsive objects able to react to external stimuli by modifying the formal shapes while conserving the morphogenesis logic."

Communication media: The digital twin is modifying the approach to communication media toward a more collaborative media strategy. Parallel to the availability of field data and the shifting of digital focus in yacht design processes, the 4.0 enabling technologies and new manufacturing paradigms of Industry 4.0 could enable a novel approach to the communication, and therefore collaboration, tools for yacht design and engineering. In the journey depicted in the roadmaps, it acts as a medium virtually replacing the paper draft and drawing and project render. As a shadow of the projects embedding all the physical and digital assets, the digital twin could be furthermore used as a co-design tool between yacht designers and engineers as well to involve customers or manufacturing teams and supply chain in the project definition. Furthermore, the Digital Twin supports the visualization and management of the vessel throughout the whole life cycle, becoming a valuable tool in the maintenance stages.

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7. Conclusion and further steps

The paper presents an explorative study of the topic of Industry 4.0 in the yachting field. The research focus raised from an intuition about the need to foresight the role of the new digital technologies and new manufacturing models in the transformation of the yacht design sector to understand and guide the undergoing digital transformation, filling the literature gap where no scientific publications consider the impact of Industry 4.0 in the yacht fields on its entirety.

Due to the freshness and the unexplored complexity of the Industry 4.0 topic in the yacht design practices, strategic thinking and collaborative research activities to explore alternative futures were prioritized, using case studies analysis and scenario-building participatory workshop as main research methods. With the purpose of building a robust forecasting framework, a card-sorting analysis on 4.0 enabling technologies applied in the yachting industry was carried out to ground the knowledge on relations between industry 4.0 design principles and digital technologies. This activity led to the discussion on opportunities and trends for the Yachting 4.0 forecasting framework. This first research result was used in the scenario-building participatory workshop as a guiding backdrop.

Then, three scenarios and three roadmaps toward a computational morphology system are presented. The definition of the Yacht Design 4.0 Roadmaps was, in itself, a design matter. Sustained by all the qualitative data and knowledge collected by case studies and by the co-design visioning activity of a scenario-building workshop, the roadmaps represent an unavoidable subjective synthesis of the research results, conceived as a guide in bridging the gap between the current situation and the visions developed. Furthermore, they contain a reflection on novel yacht design practices affected by the new manufacturing models and digital technologies of Industry 4.0 as the main contribution of the study in the yacht design field.

The research evidence highlights three central possible (future) shifts in the yacht design practices, which are as follows:

- the input data are moving from analogic to digital, reframing the focus of the designer practice from the measured data to the inferred data;

- the use of parametric and generative design tools is shifting the "digital doing" from digital drafting to digital logic driving the process toward a more digitally conscious and virtually collaborative environment;

- the digital twin is modifying the approach to communication media toward a more collaborative media strategy.

The research achievements resulted positioned on a conceptual level. The founding has numerous links and overlapping with the research on Computational design and morphogenesis logic design [35]. For this theoretical nature of the research, the results still need to be pragmatically tested and verified by applied research projects both the shipyards and in design studios. Plus, the workshop discussions point out numerous criticalities at different levels that should be considered for future study in the field—(i) the emerging role of digital yacht designers and the new skills necessary to face the digital transformation, (ii) the design of specific tools for yacht design co-creation, (iii) the issue of data using and data protection, and (iii) the challenges on cybersecurity in the maritime sectors.

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Chapter

Applied Mathematics Tools in Digital Transformation

Francesco Calabrò, Maurizio Ceseri and Roberto Natalini

Abstract

Digital transformation is a process that companies start with different purposes. Once an enterprise embarks on a digital transformation process it translates all its business processes (or, at least, part of them) into a digital replica. Such a digital replica, the so-called digital twin, can be described by Mathematical Science tools allowing cost reduction on industrial processes, faster time-to-market of new products and, in general, an increase of competitive advantage for the company. Digital twin is a descriptive or predictive model of a given industrial process or product that is a valuable tool for business management, both in planning—because it can give different scenario analysis—and in managing the daily operations; moreover, it permits optimization of product and process operations. We present widespread applied mathematics tools that can help this modeling process, along with some successful cases.

Keywords: data mining, digital twin, modeling simulation optimization (MSO), numerical linear algebra, scientific machine learning

1. Introduction

What is digital transformation? According to Ebert and Duarte [1], Digital Transformation (DX) is "about adopting disruptive technologies to increase productivity, value creation, and the social welfare". The above definition is quite general meaning that DX can be adopted in many circumstances and by many actors: governments (from local to national level), multilateral organizations, industries. Digitalization, and in particular the concept of Digital Twin, has applications in many different fields [2]: Health, Meteorology, Manufacturing, Education, Cities and Transportation, and Energy.

Indeed, DX is having a huge impact on society at large. For instance, concerning labour force, a report from the World Economic Forum [3] states that by 2025, as a consequence of digitalization, 85 million jobs will be destroyed, while 97 million new jobs will be created worldwide. Thus, new competencies and skills will be necessary in a digitally transformed world. Among the top skills listed in the WEF report are the following: Critical thinking and analysis, Active learning and learning strategies, Analytical thinking and innovation, Complex problem-solving, Systems analysis and evaluation. We can observe that a person with a background in mathematics possesses the above skills. More generally, STEM education will offer great opportunities in DX. A recent study [4] shows that in the US the automation and the use of robots in the productive environment has increased the enrolment at Universities and higher education levels in the field like Computer Science and Engineering. This shows an increasing awareness of the workforce of the importance of updating labour competencies.

This paper focuses in particular on the digital transformation of Industry. Throughout this paper, the term "Industry" means business and commerce, public and private research, development, and production facilities; in practice, all the activities that lie outside the field of academic research and education. For the industrial sector, DX leads to huge changes in how a company is managed and can also significantly affect customer satisfaction and product quality. The effects of digital transformation can be seen at many levels of an organization: the way employees work, how business processes operate, and how to collect, analyze, and use data. All the above considerations imply that DX does not mean simply the digitization of information. This is just a first indispensable step of a bigger transformation of the way a company is managed: in short, DX requires a digital culture within an enterprise [5].

Digitalization is enabled by a series of technologies:

- **IoT**: different objects in a system (a product or a manufacturing environment) are connected by sensing devices to the Internet and can interact with one another; this allows the control of the system throughout its life cycle.

- **Big Data**: the huge amount of data collected every moment on the system are a powerful tool to understand the process, and extract information.

- **Cloud**: the data collected has to be stored properly and safely and made available to the users; the user, in turn, may operate on the data through, for instance, simulations to understand what is happening on the system under control.

But one of the most important technologies enabling the Digital Transformation is Mathematics. Modeling, Simulation, and Optimization methods (MSO) have demonstrated their usefulness for solving problems in real life: forecast of air pollution, image processing, filtration processes, cultural heritage conservation, just to mention a few. MSO are becoming very important in a digitalized world, since they make it possible to extract information and knowledge from the data collected. In fact, in the last years research have developed new mathematical tools to be applied, for example, in Digital Twins [6, 7]. And some authors have talked explicitly of an "Era of Mathematics" [8].

This paper will give an overview of the mathematical tools that can be applied in a digitally transformed enterprise. It is organized as follows. Section (2) will describe the two main approaches of applied mathematics to digitalization: Physics-Based and Data-Driven. We will depict the main differences and how they can be combined to increase their effectiveness, with an example from an Industrial case. Section 3 will introduce some tools from linear algebra that can be applied to process collected data. Finally, in a concluding section, we will summarize our points and stress the importance of promoting Mathematics towards Industry.

2. Physics-based versus data-driven approach: competition or collaboration?

The Digital Transformation implies the use of mathematical models and methods to take advantage from the (possibly huge) amount of data collected by an enterprise about its own processes. When an enterprise wants to digitalize its processes it may apply a physics-based approach or a data-driven approach. The above approaches imply different methods to deal with a problem, each one with its pros and cons [9]. In recent years, however, Hybrid methods have been developed building on the two approaches. The hybrids have been developed in such a way to sum up the advantages of both model-based and data-driven approaches while reducing the disadvantages.

2.1 Physics-based

With the Physics-Based (PB) approach, we mean a description of the process or device based on first principles. Thus, the digital counterpart of the process is a mathematical model that describes the physics of the system taking into account all the relevant scales. Such an approach is also named Model-Based to emphasize the role of mathematical modeling.

Thus given a system to be digitized, the enterprise has to translate it in a mathematical model with a variable degree of complexity. The complexity of the model depends on the problem at hand and on the business objectives. The model can be used to monitor the performances of the system and then decide how to manage possible anomalies. How possible anomalies can be detected? Sensors are positioned on the system to collect data about its functions. The data are then compared with model output evaluating the residual, *i.e.*

$$r_i = |u_i - d_i|, \quad \text{for} \quad i = 1, \ldots, N \tag{1}$$

where u_i is the outcome of the mathematical model, d_i is the data collected by the sensors, and N is the number of data collected. If the residual exceeds a given threshold, then the system does not “behave properly” and some countermeasure has to be implemented.

Physics-based models can be powerful tools to create a Digital Twin. They can give great support in the first design of the digital system; in fact, they can give useful information on the processes to be described without great moles of data. As an example, physics-based modeling can give a first idea on what variables shall be monitored.

Physics-based models are characterized by transparency: this makes straightforward the interpretation of results.

Generalization is another important characteristic of PB models. The underline assumptions, as well as the approximations due to the development of the model determine the extent to which a model, can be generalized to other cases not previously considered. In general, in a PB approach, the limits of applications of a model are known in advance and this makes clear the range of problems it can describe.

One of the main problems of such an approach is the complexity of the resulting system of equations; in the presence of multiple processes interacting with one another (multi-physics systems) and at multiple spatial and/or temporal scales (multi-scale systems), the difficulty in solving the equations will increase very rapidly. Some techniques have been developed, such as Reduced Order Modeling, to diminish model and computational complexity and end up with a more manageable system of equations, while maintaining the accuracy of results [10].

Nevertheless, such an approach is the one that permits a automotive industry to do crash test only via numerical simulations and new applications of the PB are growing up. For example, we are now able to simulate the whole heartbeat where all the physical parts (electrophysiology, the passive and active mechanics of the cardiac muscle, the microscopic force generation in sarcomeres, the blood flow in the heart chambers, and the valve dynamic) concur to the final simulation, see [11].

PB approaches have been applied also in the field of building automation: in [12] the authors focused on predictive maintenance of biomass boilers trying to minimize user discomfort.

2.2 Data-Driven

Data-Driven (DD) approach implies the use of methods from Machine Learning or even Deep Learning to exploit directly the data collected by sensors on system performance. Artificial Intelligence tools are suitable when very high amounts of data are available and can be used to find hidden patterns in the sample that cannot be discovered otherwise. Such a pattern can be refined whenever new data are collected. In such a way, we can say that the tool "learns from experiences".

The methods applied are diverse and comprises the following:

- Support Vector Machines
- Artificial Neural Network
- Convolutional Neural Network
- Recurrent Neural Network
- Generative Adversarial Network

The main advantage of the DD approach is the ease with which the solutions can be found, compared with the first principle approach. They have proven to be a very good alternative to PB models. If enough data are available, tools like neural networks can find hidden structures in very complex problems, where it is difficult to describe exactly the underlined physical structure. To give an example in the field of Material Sciences, in [13] the authors developed a Neural Network to simulate a Cellular Mechanical Metamaterial (CMM) and compared the performances with Direct Numerical Simulations (DNS), usually applied in this kind of problem. While the DNS needs about 10^5 Degrees of Freedom and $5 \cdot 10^2\ s$ to describe the mechanical properties of CMM, the Neural Network scheme needs only 290 DoF and about 6 to 8 s to provide a solution.

The ability to generalize a DD model is very limited. A DD model can describe circumstances only spanned by the data already available. It will need a large number of new data to take into account a more general setting. The need for (possibly large) amount of information is an overall limit to the development of the DD approach; sometimes, one does not have sufficient data to describe properly a given process.

Another problem is the lack of transparency. DD model builds in general so-called *black-boxes* that do not permit a clear interpretation of results. This led to the development of explainable AI [14].

According to Gartner [15], thirty-seven percent of companies have implemented AI in some form, translating to a 270 percent increase over the last four years. Customers are accustomed to bots and AI mechanisms that provide, among others, recommendations on services such as Netflix or Spotify. Not surprisingly, 31 percent of companies plan to increase the share of artificial intelligence in their business.

2.3 Hybrid approach

Recently, some researchers attempted to compare the two approaches in order to understand the advantages and the disadvantages of both. For example, in [16] the authors compared PB and DD approaches to the problem of fault detection and isolation in an automotive application. They found the same performances for both approaches in terms of detection and robustness and described the main shortcomings of both. However, Moallemi and coauthors [17] applied both Model Based and DD models to the problem of Structural Monitoring of a building; they found that Model Based approach results in best performances and point out that scarcity of data limits the behavior of DD algorithms. Thus, the debate is still open on what is the best approach for digitalisation.

The recent tendency, however, is to take advantage of the benefits of both by building hybrid methods that mix together. First principles with data-intensive modeling [18–20]. In [21] the authors survey the research literature on this topic and propose a taxonomy of the developed methods. The integration of PB and DD approaches has several applications. PB models of complex processes require approximations to have a usable set of equations. Approximations are necessary whenever the process is not completely understood in all of its elements. This will introduce bias in model results. Another issue is due to the presence of physical parameters that have to be estimated some time with a small amount of data. On the other hand, Machine learning tools need a large amount of data to reproduce with precision a given process and have limited generalization capabilities. The use of DD techniques in combination with first principle modeling may help to overcome such limitations and this has been shown to be very useful in practice.

One attempt is the so-called *Physics-Informed Neural Networks* (PINN) [22]: a deep learning framework for the resolution of PDE in several application (fluid dynamics, quantum physics, reaction–diffusion systems, etc.). Neural networks are defined by minimizing a loss function incorporating physical constraints. If one wish to solve an equation of the type $\mathcal{A}(u) = 0$, the solution is given by the minimum of the following function

$$\frac{1}{N}\sum_{i=1}^{N} |\mathcal{A}(u(x_i))|^2 + \frac{1}{M}\sum_{j=1}^{M} \left|u\left(x_j\right) - u_j\right|^2 \tag{2}$$

where $\left(x_j, u_j\right)$ for $j = 1, \dots, M$ are training data (including initial and boundary conditions), and (x_i) for $i = 1, \dots, N$ are points where the solution is defined.

The interplay of Pb and DD approaches has been employed in Unmanned Aerial Vehicle (UAV) management; in [23], the authors present a Component Based

Reduced Order Model coupled with Baysian state estimation to allow a small aircraft to adjust dynamically its trajectory.

Hybrid methods have been applied to describe a spring-mass system subjected to damping that evolves according to multiple time scales [24]; such an application is relevant for many industrial settings and is generally very difficult to solve numerically.

2.4 An example in predictive maintenance

Through the technologies described it is possible to solve usual problems of engineering and computational mechanics but also to explore new fields in which up to now mathematical modeling had not been able to replace the experience or the direct control of the mechanism. One of the most interesting areas is that of predictive maintenance [25], already mentioned above. In some sectors, such as in aircraft maintenance, the benefits of having guidelines available to ensure the correct functioning of circulating machines are well known: in civil aeronautics, periodic checks and periodic replacements, for example, of bolts or panels subjected to greater stress is an established practice, but this practice comes from the combination of experience and modeling. On the other hand, it is well known that it is not at all easy in a complex system to keep all the components under control to have guarantees on correct functioning and to prevent possible failures and/or breakages. Machines are often equipped with many sensors that monitor correct operation, signaling anomalies on what each sensor is capable of measuring. Unfortunately, it is often only from the combination of information that the general picture is obtained, and therefore if only the single sensor is monitored, this information collected is not really helpful in decisions. Some industrial sectors, such as boating or highly automated production, would greatly benefit from the possibility of preventing critical situations before failures occur that can put in danger the correct functioning of the machinery. The modeling available to complex tools—which work on different scales and interact with each other—often has to overlook some effects and does not allow predictive models so accurate as to be able to help decision makers determine if or when to intervene with substitutions or repairs. Most of the time one can notice a problem when it is already too late.

The recent literature on predictive maintenance foresees the possibility of combining the effect of a control on the physics of phenomena, possibly linked to the information of the sensors, and of an experience given by the analysis of the available data processed through artificial intelligence. For example, in [26] the authors describe the use of hybrid techniques for controlling the operation of Computer Numerical Control (CNC) machines. These are fundamental briks in modern industries (from Wikipedia): "CNC is the automated control of machining tools (such as drills, lathes, mills and 3D printers) by means of a computer. A CNC machine processes a piece of material (metal, plastic, wood, ceramic, or composite) to meet specifications by following coded programmed instructions and without a manual operator directly controlling the machining operation." Authors in [26] present how it is possible to build a digital twin that provides information on the expected behavior of the machine and at the same time, through the data collected by the sensors inside the machine, the on-situ behavior of the machine. Then, by taking a comparison of the two, this reveals a good ability to highlight anomalies, based on the physical modeling. At the same time, however, the acquisition of a large amount of data through sensors allows the elaboration of a database that also includes a sort of forecasting model: this increases the knowledge of the ongoing process and helps in prediction.

The use of hybrid approach helps to meet the targets of predictive maintenance:

- Fault diagnosis
- Fault forecast
- Intelligent decision
- Intelligent maintenance.

3. Applied linear algebra tools

Now we consider how the tools coming from linear algebra can manage to solve the problems considered in the previous section. We consider both problems, namely the search of a model that can justify some available data and the case where the model is given and some prediction is done via numerical computations. What we present next is inspired by [27, 28], where readers can find full details of the topics introduced in this section.

3.1 Modeling with linear functions

First, we consider that a dataset is given; instances $\left(x^{(i)}, y^{(i)}\right)$ are known $\forall i = 1, \ldots, M$. As previously discussed, such dataset is described with numbers, and we identify it as input x and y is the output. Each of the inputs is vectors of numbers $x^{(i)} \in \mathbf{R}^d$ while we consider the output to be a number $y^{(i)} \in \mathbf{R}$. The dataset then can be described as an input matrix $D \in \mathbf{R}^{M \times d}$ whose rows are the instances and the columns are the features, and a column vector Y that stores the output.

Our modeling problem is to describe the dependence of the output from the input, so to identify a mathematical law $F : \mathbf{R}^d \to \mathbf{R}$ in good agreement with the available dataset $F\left(x^{(i)}\right) \approx y^{(i)}$. The most simple mathematical law that we can introduce would be the linear function. This is completely described by the coefficients $w \in \mathbf{R}^d$: $F(x) = \sum_{j=1}^{d} w_j x_j$. If we impose the agreement with the data, we have that the unknown coefficients solve the problem:

$$\text{Find } w \in \mathbf{R}^d \text{ such that } Dw - Y \approx 0 \qquad \text{(Linear System PB)}$$

Such a problem, if settled out in the square ($d = M$) and exact framework, is the well-known resolution of linear systems. We prefer to write the search problem in an approximate way, so we use the $\approx$ symbol, because usually we consider inexact data or non-square datasets, so that existence of the solution is not guaranteed. In the next section we discuss the resolution of the linear (approximate) problem. Finally, when the w are calculated, for a new instance $\bar{x} \in \mathbf{R}^d$ the model would predict $\bar{y} = \sum_{j=1}^{d} w_j \bar{x}_j$.

3.2 Model approximation

When a model is given, this is used to predict the behavior of the quantity of interest for forecasting, i.e., in unseen cases. Mathematical models are relations involving, in many cases, operations that are not tabled or easily computable. In order to understand how the tools of applied mathematics apply in such cases, we can start from a general formulation where the quantity of interest is a u^* (an unknown function in the general case or a vector/scalar) that is the solution of a problem: $\mathcal{P}(u^*, \delta) = 0$ where δ are the given data.

$$\text{Find } \alpha \in \mathbf{R}^{\mathrm{N}} \text{such that} \quad u(x_i) \equiv \sum_{j=1}^{N} \alpha_j f_j\left(x^{(i)}\right) - y^{(i)} \approx 0 \ \ \forall i = 1 \dots M$$

To begin with a simple example, consider the approximation/extrapolation of data. As in the previous section, the inputs are made of vectors of numbers $x^{(i)} \in \mathbf{R}^d$ while we consider the output to be a number $y^{(i)} \in \mathbf{R}$ so that the known data are $\delta = \left(x^{(i)}, y^{(i)}\right)_i \ \forall i = 1, \dots, M$. Eventually, the outputs $y^{(i)}$ are evaluations of a "black box" function that we want to describe in a different way. In the previous section, we considered the resolution of a liner problem in order to look for a linear model that could justify the dependence of the output by the input data. In this case, we start from different knowledge and look for a non-linear model that gives "exactly" the dependence of y from x. The approximate solution will be a function $u \approx u^*$ that can be described by a finite set of coefficients. We look for u such that $u\left(x^{(i)}\right) \approx y^{(i)}$, where $u(x) = \sum_{j=1}^{N} \alpha_j f_j(x)$, i.e., u is a linear combination of N fixed functions $f_j(x)$. The coefficients of the linear combination, $\alpha \in \mathbf{R}^N$ determinate the solution of our approximated problem u. One way to fix such coefficients is to impose accordance with the available data:$\sum_{j=1}^{N} \alpha_j f_j\left(x^{(i)}\right) = y^{(i)}$.

This problem is exactly in the same framework as the ones seen in the previous section: a matrix problem where the matrix is the so-called collocation matrix $\Phi \in \mathbf{R}^{M \times N}, \ \ \Phi_{j,i} = f_j\left(x^{(i)}\right)$.

Remark. The choice of the functions f_j strongly affects both the quality of the solution and the ability to solve the discrete problem easily. Usual choices are polynomials or piece-wise polynomial functions. Nevertheless many systems of functions can be used instead and the results on the capability to approximate general functions, known as the Universal Approximation Theorem (UAT), are available. One of the reasons why the Neural Network (NN) functions are widely used in numerical approximations is due to the fact that there are available UAT results in this case. We remark that in the general case of NN also some parameters inside the functions can be tuned so that the overall determination of the network is a nonlinear optimization problem.

Moving from the approximation of a given function to different scientific models, we encounter the case of equilibrium laws based on first principles, as described in the previous section on Physics-Based approach. Also in this case the unknown is a function but in this case, the model is written as a solution to a mathematical problem $\mathcal{P}(u^*, \delta) = 0$ that involves some operators applied to the unknown function: derivatives and/or integrals (that are linear operators) and eventually nonlinear transformations. (The problem of interpolations described at the beginning of this section can be sought as the resolution of a mathematical problem that involves only evaluation of functions on sites, which is a linear functional.) Also in the case where only linear operators are considered, approximated problems for integration and derivation are needed because both operations are intrinsically infinite-dimensional [29, 30]. In general, two main roads—or combinations of these two—can be taken for the numerical resolutions of problems that involve the use of operators:

- instead of considering general functions, look for a solution written as a linear combination of simple functions where the operation can be done simply $\Rightarrow u = \sum \alpha_i \phi_i \approx u^*$;
- instead of considering exact modeling approximate the operators and look for solutions in particular cases, ad example in fixed sites $\Rightarrow \mathcal{P}_N \approx \mathcal{P}$.

Applied mathematics tools aim to introduce methods that translate the original model in some approximation that is consistent with the original formulation and gives an accurate approximation of the unknowns. The initial problem $\mathcal{P}(u^*, \delta) = 0$ is then reformulated in an approximate way ($\mathcal{P}_N \approx \mathcal{P}$) and the sought solution is an approximation of the mathematical solution ($u \approx u^*$). The final resolution step, in most cases revels in the resolution of a linear problem as the ones seen before.

3.3 Numerical resolution of linear systems

Because many problems seen in this excursus are finally modeled via linear systems, we aim to present some of the ingredients that can be used for the resolution of linear systems. The problem written in (Linear System PB) is the one that we aim to solve.

As commented, the unknown vector w has to solve the problem of interpolating the available data with a linear function, i.e., if $D_i^{(j)}$, $j = 1, \dots, d$ are the features of the $i-$th individual and Y_i is the output, then w_j are such that $\sum_j w_j D_i^{(j)}$ should be close to Y_i $\forall i = 1, \dots, M$. The first case that we consider, is the one where we have more parameter to fix than available information, so that the number of features d is greater of the number of individuals M; the problem is also referred as overparametrized.

First of all we introduce the rank $r \le d$ of the matrix D: this is the number of columns of the matrix that are linearly independent, i.e., columns that cannot be written as a linear combination of the other ones. Thinking of the matrix as a collection of features from individuals, the rank would be the number of information that we collect that are linearly independent. Because our aim is to find the coefficients w_j that solve the linear system, if we call $D^{(j)}$ the $j-$th column of D, the linear system can be written as $\left[\sum w_j D^{(j)}\right] - Y \approx 0$ thus only columns that are linearly independent give useful information for the determination of the w. The real dimensionality of the problem, the number of degrees of freedom that can be sought, is then the rank of the matrix.

An important feature when data are collected with some error—or "noise"—is that the rank of the matrix could be affected by this error: some columns can be linearly independent only for effect of the randomness of the noise. Then, a different preliminary analysis—the so-called feature selection—that reduces the dimension of the columns could be necessary. One possible way to proceed is by exploring the Singular

Value Decompostion of the matrix and, in particular, the order of magnitude of the singular values. All these procedures that avoid the presence of redundancy on the feature collection, end up with the so-called active features. When this preprocessing of the data is done, we need to solve the problem of the determination of $d^* \leq d$ coefficients w^* to be fixed from the M linear equations: a linear problem of the type $D^* w^* - Y \approx 0$. If d^* is still greater or equal to M, the problem—which is referred as square if $d^* = M$ or underdeterminated if $d^* > M$- has always an optimal solution, i.e., a solution to the matrix problem $D^* w^* - Y = 0$. If the problem is square, the solution is unique. It has more solutions when $d^* > M$: to select between these solutions we can introduce the square problem $(D^*)^T D^* \tilde{w} = (D^*)^T Y$, where $(\cdot)^T$ stands for the transposed matrix. Such equations are referred as "normal equations" for the non-squared linear problem. The solution $\tilde{w}$ solves a square linear system and is one of the possible vectors w^*.

Overdetermined linear problems are the ones where the number of features (or active features as described above) are less than the number of individuals, that is, the number of rows of the matrix M; the problem is also referred as overfitted. To focus on such an overdeterminated case, we can focus on the scalar case, where $d = 1$. The coefficient $w \in \mathbf{R}$ is, then, the slope of the straight line that we want to construct in order to give a law of direct-proportionality between x and y: $wx_i = y_i$. This problem admits a solution only if $M = 1$ or if the points (x_i, y_i) are aligned (and aligned to $(0, 0)$).

In the general cases, in order to solve the linear problem $D^* w^* - Y \approx 0$ one has to introduce an optimality condition and try to solve the problem of "best fit". After some computation, what turns out to be a good solution is the solution of the normal equations as introduced in the underdeterminated case.

4. Conclusions

What about the need for companies of such technologies? What we experience every day is that new technologies are deeply changing markets, as if this is "second wave of digital transformation". In fact, Robotics, Machine Learning, Big Data and Artificial Intelligence are becoming more and more common.

Using properly DX, companies have the opportunity to optimize operating costs and thus increase process efficiency via new services. Additionally, the digitalization of company data produces the so-called "digital capital" made of huge amounts of information from various sources, which increases the possibility to settle out predictive models. This allows companies to better meet customers' needs. DX is the present for companies that aim to remain competitive, and the use of simple mathematical tools opens up great opportunities in unexpected fields.

However, Enterprises are not completely aware of this point and how they would benefit from the application of Mathematical research in their daily operations. In the last few years, a new professional figure emerged world wide to promote:

- MSO towards enterpises, and
- Industry-Academic Collaborations.

The above role is played by the *Technology Translator*. A Technology Translator has strong competencies of Mathematical research and on the other hand good knowledge of industrial processes; thus, he/she is the right person to talk both with mathematicians and enterprises. Since Academics and Industrialists have different languages,[1] the need has emerged for a professional figure that can translate Industrial problems in mathematical terms enabling the cooperation among the two world. There are several Institutions in Europe employing Technology Translators. In Italy, the National Research Council of Italy promotes the project *Sportello Matematico per l'Innovazione e le Imprese*.[2] The main objectives of Sportello Matematico are: Promoting Mathematical Technologies as source of Industrial Innovation; Activating cooperations between Enterprises and Research Centers; Facilitating the employment of Mathematicians in Industry [31]. The work of Technology Translators contributes to the change of perspective required by the complex challenges of Digital Transformation.

[1] This is also related to the fact that Industry and Academia have different objectives and timescales.
[2] www.sportellomatematico.it.

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Chapter

Perspective Chapter: The Sovereign Way - How Diversity in Construction Is Key of Success in the Digital Age

Bianca Christina Weber-Lewerenz

Abstract

It is true that women no longer have to be looked for with a magnifying glass in the executive floors of German businesses; however, their share is still small. The digital age holds great potential for increased inclusion and closure of the "Gender Leadership Gap," especially in the construction industry. Industry standards, including global ones, are being examined to achieve more inclusive corporate governance models. The construction industry, which is regarded as one of the most traditional and conservative, male-dominated industries, serves as the best example for a long-overdue need for dynamic restructuring and action related to women's leadership. This research is an approach to outline the framework answering the need to redefine, recalibrate and reshape this industry by increasing women's role in the social, digital and business transformation processes. This approach is the most important finding as it bridges the current divide and facilitates movement from discussion and advocacy toward application and practice.

Keywords: women leadership, responsible leadership, digital innovation, digital transformation, digitization, AI, construction industry, diversity mandate, ethics, inclusion, diversity, blockchain

1. Introduction

Despite the good order situation, construction companies are exposed to persistent cost pressure and a shortage of skilled workers. New digital technologies and artificial intelligence (AI) improve operational efficiency, offer new business models and provide training for new qualification requirements that correspond to new job profiles. The construction industry is the key industry in Germany; it plays an important economic role. For example, construction investments by the German economy added more than EUR 387 billion in 2020—the highest level since the 2008 recession as per the statistics by the Main Association of the German Construction Industry [1]. Around 10% of the German gross domestic product is used for construction work. In 2020, the share of gross value added in the construction industry in Germany was around 6.1% of Germany's total economic gross value added. With almost 2 million employees, the construction industry supports the overall economy in the COVID-19 crisis but is responsible for 38% of all global energy-related CO2 emissions. Energy and climate, digitization and the need for skilled workers directly affect the construction industry. The industry could benefit significantly by implementing the strategic decision-making processes, planning and operating phases more efficiently by standardizing both digital technologies and methods of AI in more diverse environments, pushed by legal regulations. In short, diversity and a new culture of thought are essential for the future-oriented portfolio in the construction industry to make the digital transformation holistic, successful and sustainable. Nevertheless, there is a lack of recognition of the potential of new technologies, there is a lack of courage and willingness to use them, and there is a lack of diversity.

The digital age holds great potential for increased inclusion and closure of the "Gender Leadership Gap" [2]. The construction industry, which is regarded as one of the most traditional and conservative, male-dominated industries, serves as the best example for a long-overdue need for dynamic restructuring and action related to women's leadership [3, 4]. The Status Quo listed below is evidence of the strong need to redefine, recalibrate and reshape this industry by increasing women's role in the social, digital and business transformation processes. By assessing why diversity is the key factor, this approach bridges the current divide and facilitates movement from discussion and advocacy toward application and practice. The evaluation of such assessment comes with two theses. Dealing with these goes hand in hand with significant calls for action on both legal and an overall societal level. They lay the ground for implementing diversity and follow the sovereign way to set value accents for Construction 4.0.

2. Status quo of diversity

The 25th-anniversary celebration of buildingSMART Germany on October 27, 2021, in Berlin spurred the diversity discourse on-site and around the globe with the author's keynote speech and a panel discussion on the "Success factor diversity in the construction industry" [5]. It offered approaches on how diversity in corporate culture and knowledge can help avoid discrimination and gender bias, optimize inclusion and further improve crucial aspects of digital ethics in data-driven technologies—such as fairness and transparency in AI.

Women strengthen public trust in AI, their communication skills, transparency and network breadth speak as independent characteristics for the success of female leadership potential. This is all the more important in an industry like construction, which has a very high share of the economy but lags behind digitization and AI, diversity and inclusion. The construction industry is traditionally conservative, a male-dominated industry with the attitude "Let's do it as always," "It works" and "We need a strong man on-site." The "good old boys" network and gatekeeping have a long tradition. In recent years, the industry has had to accept a significant decline in the number of skilled workers. The digital transformation creates the conditions for disruptive reforms and changes to include women, win them over to STEM and offer new career paths. Virtual reality (VR) and blockchain technology for example show a great development from the technical perspective but especially from the innovation factor's perspective carried by inclusion and diversity [6]. When it comes to global crises such as economic and pandemic crises, it is crucial to secure human and social rights. Furthermore, it is even more important to strengthen diversity, gender parity and inclusion and maintain democratic values to successfully master historical crises [7].

Nevertheless, there are prejudices and a lack of role models, although the construction industry cannot do without the qualifications, know-how and socially communicative digital high potential of women. To fundamentally rethink the technological progress that enables new business models and to keep pace with digitization in the long term, all those involved are required to promote best skills, diversity and inclusion. Thus, the digital change is also accelerating the merging of these previously separately working units. Evidence of hard facts such as increased profitability (ROI) and overall excellence in digital corporate culture rationalize the gender discussion. The need for action is high: increasing the far too low proportion of women in the construction industry in general (**Figure 1**), enthusiasm for more female students in civil engineering (**Figure 2**), toward more female mandates and

Figure 1.
Women in construction in Germany source: statistics in construction 2021, main association of the German construction industry (German HDB).

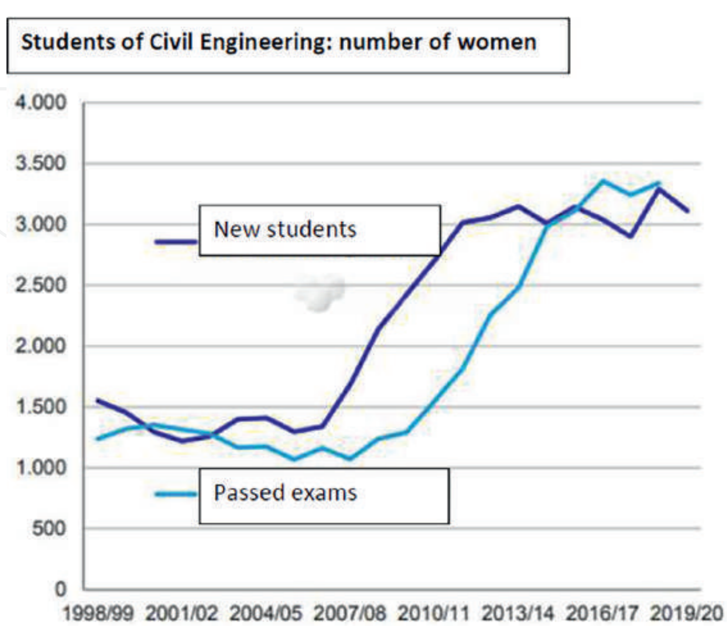

Figure 2.
Female civil engineer students in Germany source: statistics in construction 2021, main association of the German construction industry (German HDB).

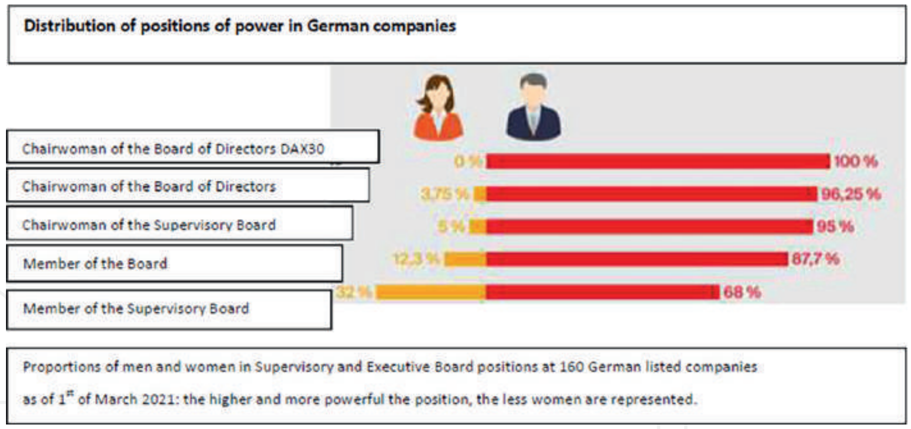

Figure 3.
Distribution of positions of power in German companies source: allbright report as of 05th march 2021 [8].

Figure 4.
Gender proportions in machine learning (ML) research source: EQUALS report 2019 [9].

board members (**Figure 3**) and closing the still serious gender gaps in AI occupational fields (**Figure 4**).

Companies that prioritize gender equality in their hiring practices and workforce also generate 41% more revenue than those that do not. Recently, McKinsey & Company found that companies with different leadership teams were 21% more likely than their counterparts to outperform their peers. Plus, they were 27% more likely to create and deliver value [10]. According to a McKinsey and Company study in 2015, AI-controlled talent intelligence immediately triples the diversity of the talent pool and at the same time lowers recruiting costs by up to 60%; diverse teams are 35% more profitable and 1.7 times more innovative; interview pools with a diversity of at least 40% tend to optimize the hiring processes.

AI is the result of human intelligence, enabled by their enormous talents and also prone to their limits. Hence, it is imperative that all teams working in technology and AI be as diverse as possible. Diversity of people does not only mean the obvious in terms of demographics such as race, ethnicity, gender and age, but also people with different skills, experiences, educational backgrounds, cultural and geographical perspectives, opinions, ways of thinking and working. The digital transformation has great potential to make the life cycle of construction projects economical and efficient and to enable the greatest possible social benefit, economic prosperity and the protection of our natural foundations of life. However, the digital age requires strengthening strategic values for a more inclusive environment and the common good. Gender mainstreaming is the answer, as this concept of gender equality at all social and political levels fundamentally and systematically takes into account the interests of women and men.

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Courage and the will to innovate-this courage is expected, especially from the German building trade. Here is a lot of strength, self-confidence and potential for innovation, as well as in other parts of the world [11]. Diverse knowledge, skills and strengths are necessary to tackle the challenges. They are key for success, weighing up decisions and exploiting the potential. Where technical feasibility and social responsibility meet, a field of tension arises. The particularly high shortage of skilled workers, the loss of attractiveness of entrepreneurs for applicants, the increasing pressure in global competition and the more necessary interdisciplinary dialog strongly clarify the need for action. With diversity in technical and interdisciplinary know-how, through diverse backgrounds, communication that "takes people with you," a good mix of personal and social strengths, human and technical transformation is filled with life and the digital era is shaped sustainably. The digital era means both opportunities and risks. Diversity leads to success.

The step-by-step implementation of various gender and equality strategies initiated by UN, EU, UNESCO, UNICEF and World Economic Forum are reason to celebrate but always combined with the task of responsibly dealing with high-tech, building, traditions and our society as a whole—and its transparency and control [12, 13]. It requires full attention to find out which technology helps the human, how and where it supports human work best, makes human work more efficient, much easier and safer, and how the human can (and must) make full use of the potential and lay new paths in the digital era. To date, there has been no lack of technical development, especially in construction. We all know where the dowel should fit. We all know where the nail on the head needs to be hit. But do we always have our compass ready for internal alignment and meaningful changes of direction and decision-making?

We live and work in complex surroundings with increasing data, more technology, faster, more tasks, more interfaces and more specialist knowledge. We devote ourselves passionately to our daily work topics, but also to shaping our future together. It is us, humans, we shape the environment in which we live and work. We daily operate in multi-complex areas of tension: between what is technically feasible and in ethical compliance, digital change and humane change, innovative technologies and social expectations.

3. Why diversity is key for success

Here are two theses: Digitization does not automatically lead to more diversity. Technology does not solve our social problems either.

We want to create value, we want useful technology that supports us, humans, we want complete data of the highest quality to make AI non-discriminatory. At the same time, we are surrounded by a complex world of data, constantly new requirements, in a less agile environment. There is a lack of knowledge, not only in construction but also across disciplines: "Think outside the box" with qualified and diverse specialists. In 33.5% of companies in building construction, in civil engineering even 37.9% lack skilled workforce according to construction industry statistics as of September 2021. Demographic change shows in October 2021: There are more retirees than trainees and students.

Many of us are not equally familiar with digitization and AI or are aware of their potentials or their unwanted effects. To unravel the aforementioned areas of tension, there is a key factor: DIVERSITY and a change in the culture of thinking. The pressure is already there:

1. Companies need to provide evidence of their social commitment and how they are fulfilling their responsibilities and inclusion.

2. Only as an attractive employer is it possible to attract new skilled workers with new knowledge.

3. It is important to reaffirm the trust of stakeholders, employees and customers, in particular by showing intangible values in annual reports.

Recent examples of successful interdisciplinary and diverse cooperation for technical innovation in construction are the German pavilion at Dubai EXPO2021: All strengths are bundled, and diverse and talented teams laid the foundation for the integrative multidisciplinary environment for sharing knowledge and strengths leading to this outstanding construction project. Same with the world's first adaptive skyscraper at the University of Stuttgart, which is used for research purposes: this project brings together interdisciplinary knowledge, for example, from engineering and mechanical engineering: Hydraulic cylinders are integrated into supports and are part of 128 measuring points, to, for example, make environmental influences on the building measurable.

These strategies are vivid samples of the Berlin Declaration at the 68th Assembly of the Federal Chamber of Engineers in October 2021 states: "*Engineering competence is an indispensable value for the design of our environment … sustainability …. a must: to consider the entire life cycle of buildings … .*"

"*City, Country, Construction - We can do more than just build!*" Everything at the Construction Industry Day 2021 revolved around innovation, added value, such as "Construction sites become new models" and other value strategies embedded in the European Green Deal [14] to minimize CO2 and become first climate-neutral continent.

Diversity is a topic that stimulates, touches and sets vibrations. So how does diversity define success in construction?

- Diversity ensures balance and creates values

- Diversity means allowing many aspects, listening, and requires mindfulness, empathy, respect

- Diversity facilitates well-balanced decisions (strengths complementing each other)

- Knowledge from many subjects, professional diversity that comes together

- The complexity of know-how, data, people, requirements, expectations, constantly new technology and possibilities, changing environmental conditions

- Diversity of interfaces enables the exchange of knowledge in times of digitization and AI; diversity is indispensable to design this technological support for people regardless of gender

- New job profiles, new areas of responsibility, new professional and personal qualifications, an adaptation of curricula and teacher qualifications

- Adaptation of training: teaching qualifications, access to education, access to media and digital working media, information

- Interface skills (well beyond specialist boundaries), broad-based networks, cooperation in various teams (complement each other, change of perspective)

- Role models, role models, best practices are in abundance (successful companies/research/innovations led by women = statistics show where and how women are the engine and key factors for technical innovations and entrepreneurial success.)

- Country and culture, specialist discipline, skills and knowledge, strengths, experience, perspectives and ways of looking at things

- Diversity brings together skills and strengths. Joint search for concrete approaches.

Diversity connects us, humans, strengthens trust, creates mutual professional benefits and supports lifelong learning. Trust, security, awareness and education are key elements for understanding and applying new technologies. buildingSMART Germany, as part of the global construction-wide competency network buildingSMART International, copes with the challenges of the digital era by sharing user practice and up-to-date research findings with its innovative members. The author contributed keynotes and scientific presentations during their events.

With a view to the two previously raised theses: Digitization does not automatically lead to more diversity. Technology does not solve our social problems either.

Isn't diversity rather an engine, one of the most important success factors in the digital age?

By paving new paths for your success as a competitive company, you are building the foundation for diversity in your children's professional lives and their career opportunities! Let us make full use of this historical opportunity, which this technical and human change offers—well thought out, and with full speed.

The German building craftsmanship, our engineering skills and our values are considered as a role model in the world. A seal of quality shines on our partners all over the world. For example in China one says, the Germans build for eternity, German products are extremely reliable, and German engineering craftsmanship deserves the highest recognition. This awareness of how German engineering and engineering ethics are valued from outside of the country, knowing, which expectations are equally directed toward us, and how we repeatedly challenge ourselves is a great motivator and inherits large responsibility. Because such responsibility means to maintain and strengthen values and constantly develop our skills. New technologies offer a historic opportunity! It is important to prove the reputation of the construction industry.

4. Calls for action

Strategies on the national, European and global levels drive diversity, gender issues and inclusion toward more innovation in AI and digital change (**Table 1**). Statistics from the AllBright Foundation 2021 show that corporate governance codes or ethical codes are not half as effective as corporate management that exemplifies these values in a diverse corporate culture.

• The 17 Sustainability Goals of the United Nations (2016)—UN SDGs
• United Nations Convention on Women's Rights (1981)
• The Pontifical Academy for Life in Rome (2020)—Rome Call for AI Ethics Guideline [15]
• Digital inclusion strategies from UNESCO, UNICEF, World Economic Forum [16]
• EU Gender Equality Strategy 2020–2025 (Union of Equality) [17]
• European Commission (2020) White Paper on Artificial Intelligence—A European Approach to Excellence and Trust (world's first proposal for a legal framework for AI) [18]
• European Commission (2021) Proposal for a regulation of the European Parliament and of the Council: Harmonized rules on AI (Artificial Intelligence Act) and amending certain Union acts
• European digital strategy 2030
• Enquête Commission of the German Bundestag "Artificial Intelligence—Social Responsibility and Economic, Social and Ecological Potential" [19]
• Data Ethics Commission of the Federal Government (2019) Report on data ethics
• AI strategy of the Federal Government
• Federal Ministry of Transport and Digital Infrastructure BMVI (2017). Implementation of the step-by-step digital planning and construction
• Curriculum: in preparation (2021) by the German Chamber of Architects: "BIM in academic teaching"
• T20 Policy Briefs for G20 summit Italy 2021

Table 1.
Calls for action source: Bianca Weber-Lewerenz.

The construction industry, which is considered to be one of the most conservative, male-dominated industries, is the best example of a long-overdue dynamic need for restructuring and action in relation to a more diverse environment. The most important catalyst is diversity in all social, digital and business transformation processes.

5. The sovereign way: new approaches to implementing diversity

Success in the digital age requires a strong push, disruptive innovations in an interdisciplinary environment with an open corporate culture exemplified by the management. Well-balanced decision-making and the full exploitation of potential are possible when advantages and disadvantages, chances and risks of digital methods and AI are thoroughly thought out, and where diversity enabling new innovations is seen as an opportunity, particularly, when it comes to creating the corporate unique selling point with innovative digital business models. In companies, long-term personnel development is one of the main focuses and is one of the approaches for the practical implementation of diversity (**Table 2**).

One of the core tasks in the digital age for decision-makers in the societal, political, social and business environment is to recognize the benefits of AI and to operationalize it in a responsible and morally justifiable manner. The ethical components of diversity are essential for the non-discriminatory design of AI. Progress helps to develop creativity and improve the quality of life. Because technical decision-making processes are about evaluating and weighing up advantages and disadvantages, opportunities and harm, freedom from discrimination and equality are top priorities. For buildingSMART, it is both mandatory and encouraging to pursue the key factor diversity more closely.

New approaches to implementing diversity
• The role model role of women in the social, digital and business transformation processes
• Enable new data-driven technologies and AI
• Diverse, integrative environments = the basis for successful, sustainable paths
• Bridging the current gap between discussion and practical implementation
• Responsible leadership, diversity mandate, ethics council
• Diverse corporate culture and management that exemplifies diversity
• Legal regulations (in addition to entrepreneurial personal responsibility)
• Key competencies, qualified staff, adapted curricula
• Increase the share in the value chain
• Aligned to the common good and sustainability goals
• Renown abroad: "A transparent and ethical AI - Made in Germany."

Table 2.
New approaches to implementing diversity source: Bianca Weber-Lewerenz.

6. Conclusion and value accents for construction 4.0

Diverse, integrative working groups ensure a variety of perspectives and thus a quality boost for research and development. The fundamentally necessary discussion about diversity and humane change in the construction industry could not be better embedded than in the digital transformation process. New technological feasibility creates new opportunities for the design, visualization, realization, use and recycling of a building. It is important to localize, implement, control, maintain and protect the sensible use of AI. It is critical to implement and enforce a framework of rules and best practices that, when organizations adopt AI tools, they are well allocated and trained, and that there is a clear strategy to demonstrate transparency about how the algorithms are designed and identify who is involved, how the software applies and data need to be fed and updated. It will be necessary to adopt a number of principles of digital ethics to guarantee diversity and equality of the sexes, guarantee data protection and data security—going well beyond the general provisions of the General Data Protection Regulation (GDPR), and also making the adoption more transparent promote measures (e.g. the IEEE Standard P7003 adopted in 2021 to avoid algorithm bias, algorithmic testing of fair, gender-independent treatment).

Ethically justifiable products are regularly more competitive, and the responsible use of digitization and AI can only be achieved through diversity. The people who fill civil engineering with life are challenged to re-think radically, face innovative technologies openly, align professional personal skills with them and build them up anew. The discourse on the design of corporate responsibility in the digital society requires a new quality of discussion. The implementation of these requirements is the key competence in Germany. The author fills this scientific niche with her research project on CDR in construction [20].

How does technology support us, humans, sustainably and in our value-based decisions in the construction industry? [21] How do we design a digital transformation in construction that makes sense, makes work safer, and processes more efficient? [22] Old questions that are more modern than ever—in the course of the digital transformation—especially under the focus of the humane transformation [23]. This debate is completely absent in the construction industry [24]; the author introduces it for the first time in the course of her research. It goes beyond the dominant financial focus by deriving signposts for meaningful and value-based digitization and AI. These offer orientation in thinking and acting, enabling them to act as a role model in Germany and to become a seal of quality for the German construction industry at home and abroad.

Nevertheless, a radical rethinking is required: the traditionally conservative attitude, hesitations and the lack of legal regulations on the mandatory use of digital methods, which are still strongly anchored in the construction industry, worry [25, 26]. These are still the greatest obstacles to more efficient building life cycles, progress and the acquisition of skilled workers. The time is long-overdue to restore society's trust, to show that construction projects can be performed professionally, successfully and sustainably. More courage and willingness to innovate would help the construction industry as a whole to regain a positive reputation.

Such a holistic approach as tackled by this research is new and builds on the previously outlined calls for action. CDR in construction enables companies to implement and live up to their responsibility for diversity, technological innovations and shaping a sustainable digital age. This field of research is still completely new in the construction industry, and there is only comparative literature in other specialist disciplines. Unfortunately, diversity in a traditional, conservative industry, such as construction still, is promoted very little, even though it is one of the most important drivers of digital change for the construction sector.

Diversity in construction is an essential element of building trust, involving various perspectives and strengths, enhancing innovation and moving technological development forward. It is key for a successful digital transformation.

Acknowledgments/other declarations

This chapter is to encourage everyone to use the full potential of women in the Digital Era—in their thoughts and actions. The unexploited reservoir of women's potential is to increase the share in the value chain for more sustainability and success at all levels.

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Chapter

Education and Training in the Digital Era: A Compass for "Building Forward Better"

Bianca Christina Weber-Lewerenz

Abstract

Knowledge is the greatest raw material. To build a secure future, you need knowledge, skills, to network and get involved in the new. Digitization with the technological and social challenges requires a rethinking and adjustment of professional qualifications at the same time. More than half of 70% of the open AI positions in companies are currently unfilled. This high number describes the dilemma and the challenges for the teaching and training of tomorrow. Are we ready for the technological challenges of tomorrow? This research found that there is significantly high potential for diverse teams, staffing the STEM fields with more female specialists and fully using specialist knowledge and personal qualifications of men and women. Last but not least, this research contributes setting up compass for building forward better by ensuring gender-independent decision-making structures in human-technology interaction and use diversity as key for reaching sustainable goals and set milestones in the digital era. The main research results consist that the foundation for diversity, inclusion and sustainable digital innovations can only be ensured by adjusted education and academic training. To achieve sustainable digital transformation with a strategy foundation, education and academic training are most essential. This research fills the gap by highlighting the importance of these two essential areas that call for immediate action: Diversity, education, and training represent the drivers for the sustainable success in the Digital Age.

Keywords: education, academic training, curricula, STEM, digital innovation, digital transformation diversity, inclusion

1. Introduction

The Italian Presidency decided at the Digital Economy Ministers' Meeting in Trieste on the 5th of August 2021 to place digitization at the core of G20 discussions. Participation in education and training for all to eliminate digital gender gaps and challenge stereotypes are, thus, not just buzzwords anymore but lived engagement. The diversity of existing regulatory approaches and technologies within the G20 means that many questions are yet to be answered: how to make digitization an opportunity for all? Fostering diversity and inclusion in the digital era is essential to protect and enlarge global value chains, create a trustworthy Artificial Intelligence (AI) ecosystem, enhance the digital to achieve sustainable growth. In other words, when using the term "sustainability of digital innovations" in this article, it refers to securing the necessary basis for the solid ground for innovations: education and training. It lays the foundation in digital era and guides as compass for "Building Forward Better."

As a Senior Civil Engineer with a background of international experience in Europe and China, the author deals with all aspects of new technologies in Construction Engineering in multidisciplinary, intercultural environments, arising with Industry 4.0. The author's field of expertise in the Construction Industry covers her own engineering company in multinational environments since 2007—after filling various management and leadership positions—and mentoring female apprentices and academics in STEM disciplines. In 2019, she took a pioneering role by starting as the Representative for *"Sustainable, Human-led AI in Construction Industry"* by investigating human-technic interaction. Therefore, in 2020, she founded the Excellence Initiative under the same name [1]. Her research examines ethical, social, and economic impacts of digitization and AI on human, societal, and technological development [2].

By assessing how and why education and learning lay the essential foundation of the digital age, the research also found out that knowledge and AI not only automatize learning processes but strengthen Corporate Digital Responsibility (CDR), diversity, and inclusion in Construction 4.0.

Pioneers are role models equally to develop and implement technical innovations. They shape the digital age as they share their experiences as Best Practices.

The research includes political strategies, but also makes new demands and work out specifically, where the advantages and disadvantages of the current curricula lie in order to provide the future educational foundation as broad as possible. With that, the acquisition of both the appropriate professional and personal social skills could succeed in the best possible way.

2. Knowledge and AI automatize learning processes

The tension between the new qualification requirements through digitization and AI and existing resources for teaching and curricula with an adequate academic infrastructure could not be greater. New job profile descriptions clearly speak of holistically thinking experts and system-integrating specialists. The learning curve for everyone involved is steep, and the demands in construction are equally high: Climate and environmental protection, sustainability with resource efficiency, thinking through the entire construction life cycle—from the project idea to dismantling and recycling, budget compliance, and efficient timeline as well as a building project of highest quality. New technologies not only may ensure, but perform such processes in a much more structured, efficient, safer, successful, and profitable way. Teaching and training carry responsible roles in order to explain these powerful technological tools, to practice first approaches and to allow making mistakes. The safe and efficient use of emerging technologies and knowing its positive and negative effects require targeted instruction within this innovative interaction between human and technology.

Why is it important to specifically integrate digital methods and AI into teaching in Civil Engineering? Because only construction experts are able to localize obstacles and weak points in construction projects, name improvements, and define potential fields of application for digital methods and AI. They know the processes, interfaces, and hurdles exactly and know "where things get stuck."

The digital transformation and the latest technologies require a rethinking of previous teaching methods, teaching aids, teaching environment (laboratories, equipment, IT), knowledge in theory and practice, practical samples of application, the relationship between theory and practice, the qualifications of the teaching staff and their openness, and networks across disciplines [3–6].

3. The path forward: education and training in digital era

The basis for diversity, inclusion, and sustainable digital innovations can only be ensured through appropriate training and further education [7, 8]. The Action Plan for digital education is an essential prerequisite for creating a European education area by 2025. It contributes to the realization of the goals of the *European Skills Agenda* [9], the *Action Plan* on the European Pillar of Social Rights and the *"Digital Compass 2030: The European Path to the Digital Decade."*

The dependencies and weaknesses of European digital capacities, competencies, and technologies are becoming increasingly clear. They see a need for action particularly in the area of AI [10].

Numerous studies and forecasts on digital transformation provide information about the extensive effects on jobs. New professional fields and task profiles are emerging; they require new knowledge and skills. Some professional fields will no longer exist in the course of digital change, but new ones emerge. They accelerate the development, use and further improvement of new digital technologies and AI, and facilitate imparting the necessary knowledge to others.

AI will not only change people over the next few decades, but society as a whole. Companies that want to forego 50% of their talent face a massive problem in the medium term. Digital twins, self-learning construction sites, automation and robotics on construction sites, VR, Smart Design, Smart Construction, Smart Operation, Smart Cities, Blockchain, AI, Next Generation Computing, 5G and 6G, IoT, AIoT, AR, VR, and XR strongly influence corporate business models and daily construction site organization, construction operations, building informatics, and technical building automatization.

Analyzing the content of curricula of selected universities and colleges, crystallize out, that terms such as BIM (Building Information Modeling) and AI are mostly not or rarely listed in the overview of lectures—both for Bachelor and Master. At the same time, it can be seen that more and more new curricula modules are being set up in construction, such as Computational Engineering or Data Engineering. The aspects of human responsibility that engineers, designers, and developers bear by the nature of profession cannot be adequately taught, e.g., with the modules for Ethics: it is taught on the sidelines, and—as interviewed experts share—is usually still an optional subject on a voluntary basis. Some teachers fear that they will have to forego their own learning content and therefore see no point. These aspects are part of an even larger package of influencing factors in education and teaching, why—at this stage—education and teaching cannot do justice to the expectations and requirements of the economy and society.

In addition, there are innovative research initiatives at universities and emerging AI hubs, digital campus locations, AI labs, increasing digital transformation competence networks, endowed professorships and chairs sponsored by corporates, high-tech offensives launched by individual federal states, and AI centers as well as completely newly created modules: "Applied AI" and "Digital Ethics," "Digital Transformation," "Human-Computer Interaction," "Digital and Data Science Engineering," "AI-based Technical Building Automatization," "Digital Process Management of Construction Projects."

4. Shared experience from user practice

It now depends on the answers we humans give, how we can fill these gaps, and the new professional fields. For the analysis and evaluation in this research work, experts were interviewed based on the qualitative method: representatives from universities, colleges, newly created chairs and professorships, professional associations, new corporate departments, and institutes. They share their opinion and tendencies they assess. Statistics and job profile descriptions in national and international newspapers and professional journals were evaluated for obtaining a picture as accurate as possible of where we "stand" in the Construction Industry. What are the concrete measures to be taken to set up adequate curricula? And what distinguishes the skilled workers and "engineers of tomorrow"?

Teizer [11], partner and head of the management of technology and innovations at VOLLACK, is active in academic teaching himself. "*AI is rarely or rarely promoted and taught in teaching. For example, architecture students at many colleges and universities still have to create and present analog designs and models. BIM is often not used. The day-to-day work that follows looks different. Perhaps one of the reasons is that decades of standards are reluctant to go crazy. And with civil engineers, the purely technical discipline way of thinking is a hindrance. In order to master the digital transformation successfully and together, however, interdisciplinary cooperation, openness with an innovative flair and the integration of new technologies are required.*"

Kiefer [12] refers to the results of the study carried out by the VDI in 2017/18 on "Engineering training for digital transformation." "*Professors, students, representatives from business environment and executives were interviewed. The feedback was sobering, as in parts of the professorships, among other things, results brought to light about insufficient knowledge, less open attitude to innovations, lack of willingness to participate, underestimated importance of the influence on engineering training and the necessary measures. The discussions have high priority, especially at universities.*" Kiefer offers further important insights: "*Engineering training has already changed fundamentally: it has been opened up, via modularized design and internationalization. Highly recommended for considering the university's commitment: the umbrella organization '4ING', the Faculty Days for Engineering and Computer Science at Universities. The German Federation of European National Engineering Associations FEANI (in German "Föderation Europäischer Nationaler Ingenieurverbände") tries to influence engineering training on the european level, to agree on the necessary qualification profiles across national borders, to level the differences between the countries, to facilitate the professional entrance for the engineers, to be armed with knowledge and skills successfully. In fact, to be fully committed designing the digital transformation process in Construction. Indeed, there are major discussions about the engineering profile at FEANI. The process of opening up to realignment and adjustments is ongoing. In addition, it is the current generation, which defines the different attitudes and attitudes toward the topic.*"

Digital transformation bears high potential to aid both economical and efficient building project life cycle and greatest possible social benefit, economic prosperity, and protection of our natural resources of life.

But at the same time, the economy is lagging behind digitization and AI, diversity, and inclusion. 60% believe that the lack of diversity in the tech workplace is a serious issue [13]. Strong support for change comes from national and international networks and associations promoting the fields of STEM, construction, and digitization. In the 2020, *Digital Education Action Plan* and the *European Skills Agenda*, the Commission announced a range of actions to ensure and develop digital skills. In the next few years, the need for skilled workers will continue to increase and corporate personnel planning will have to adopt. Digital transformation changes job profiles and creates new ones. Universities, colleges, and training centers feel this change and start expanding their curricula to accommodate the subjects of digitization and AI so that the next generation of engineers and specialists provide ethical and interdisciplinary skills in digitization and AI. This is a key competence in Germany for "AI—Made in Germany", which is recognized worldwide as a seal of quality.

The decisive factor is leadership behavior, the example of top management and clear communication of the culture of values [14]. It is the responsibility of every corporate management to promote diversity at all levels, inclusion, best qualifications, and personal competence, to maintain, to ensure sustainable and—in the interests of the common good—to increase its contribution to the value chain. Corporate environments with agile, dynamic management style, and female leadership should be a matter of course to generate high performance.

Profound insights, openness, and recommendations of the interviewed experts enabled this research to reveal these new findings and set constructive approaches as a Call for Action into the ongoing debate. The wide variety of specialist knowledge and areas of responsibility illuminated the challenges and innumerable chances of diversity from different angles.

Furthermore, the holistic, inclusive, interdisciplinary approach of the author not only empowers to educate, raise awareness, and provide orientation in dealing with digital transformation but adds value to this new field of scientific research.

Algorithms, which make AI possible, are daily routine for computer scientists, but only a negligibly small proportion of society is familiar with AI and speaks this expert language. Trust in this new technology therefore is imperative but can only be established and built where it is explained and awareness is formed. In total, 125 million girls of primary and secondary age in the developing world are out of school. Girls' exclusion from education begins early and increases over their lifetime (**Figure 1**). While the vast majority of adolescent girls of upper secondary age begin primary education, fewer than half make it to the upper secondary level where STEM skills can be further solidified.

It is essential to give access to girls and women around the globe to learn and utilize these technologies; they possess high communicative, social skills as well as significant high human-driven decision-making process dynamics and are catalysts for highly dynamic and efficient learning processes, which is the real core of this innovation.

The young generation has high expectations of teaching and training in handling and transferring knowledge about both future key technologies and offer constructive solutions and gain required professional and personal skills. The best indicator for job seekers is companies that are already actively shaping the digital transformation, using methods such as BIM, helping to develop the first AI technologies, defining potential fields of application, and developing new business models as a result. The opportunities are significant and diverse for young skilled workers and engineers to prove their qualifications and enlarge the value chain by their contribution to success.

It takes people, fully participating to reach these goals, platforms, visionaries, and men of action from fields of teaching, education, business, politics, and society. *We see a strong need for the discourse, this is the only way to constructively investigate the question of*

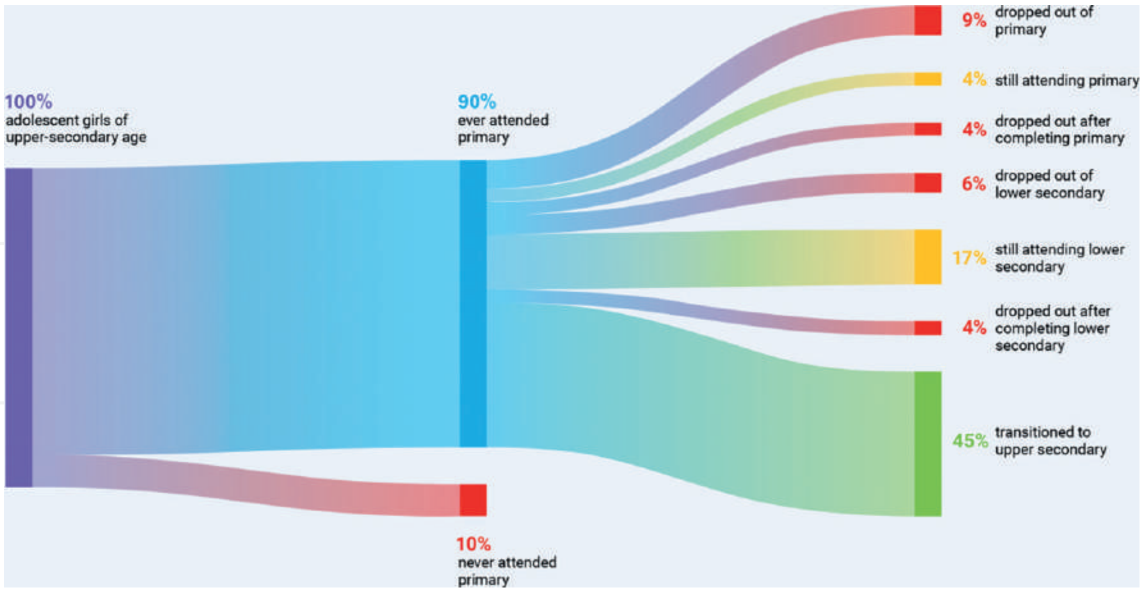

Figure 1.
Education pathways of girls in: the story of disparities in STEM, mapping gender equality in STEM from school to work source: UNICEF 2020 [15].

the qualification profile ... of the "engineers of tomorrow", which digitization and AI require. Decision-makers have a responsibility. Certain things taken for granted from the past will no longer apply in the future ... Innovative technologies—hand in hand with ethical questions—must generally be included in teaching. That has not happened yet. Mistake and problematic: it is a process in which everyone, and not just individual, has to deal with the effects of digitization and AI. Reservations, an attitude of rejection, waiting, or the attitude "we don't need" have no chance in this process that affects all of them," state Lautwein and Fox [16].

5. Algorithm complexity and gender bias

Digital transformation sets flag for disruptive reforms in the educational landscape. Best Practices are evidence for best results in increasing both personal social and expert skills. Axel Wallrabenstein sets impulses: "*Diversity in management bodies is not only important, but essential for the success of companies and for our society.*" His counterpart Rainer Esser follows, "*Companies that want to fore-go 50 percent of their talent will face a massive problem in the medium term*" [17].

New approaches offer the historical chance to break boundaries, move forward global digital competition, add value to the system of computer algorithms, and increase its share in the value chain. Women are underrepresented, so there is less data, data of lower quality, not free of bias. Thus, the results are unpredictable and unexpected. There are serious concerns regarding the scalability of taking automatically biased decisions that can affect large sectors of the population, particularly minorities and more vulnerable communities. A growing body of evidence is indicating that algorithms are increasingly affecting decisions by replicating unequal or unfair treatments [18].

In line with the European Commission' priority to strive for a "Union of Equality" by its *Gender Equality Strategy 2020–2025*, the author's Memorandum (**Table 1**), shared with the *T20* Task Force Digital Transformation in preparation of the *G20 Summit* in October 2021, focus on:

• Develop technologies and algorithms to evaluate and address bias in AI-based systems. These methods will help addressing gender in AI-based systems and support the deployment of such bias-free AI-based solutions.
• Develop standardized processes to assess and quantify the trustworthiness of the developed AI systems, in particular assessment of bias, diversity, non-discrimination, and intersectionality—based on different types of bias measures. Consider diversity and representativeness of data, ensure the reliability, traceability, and explain ability of the AI systems. Include mechanisms to flag and remove risks of biases and discrimination.
• Develop recommender and algorithmic decision-making systems, which reduce bias in the selected use case.
• Conduct trainings and awareness rising on preventing gender and intersectional bias for AI researchers, students, and practitioners in line with the Digital Education Action Plan 2021–2027.
• Cooperate with relevant partnerships across industrial and digital sectors, including digital professional associations (e.g., IEEE), computing industry, hi-tech start-ups/SMEs etc., to further promote the use and uptake of the developed tools.

Table 1.
The memorandum, shared with the T20 task force digital transformation in preparation of decision papers at G20-summit in oct 2021. July 2021 source: Bianca Weber-Lewerenz and Ingrid Vasiliu-Feltes.

6. Disruptive changes in curricula

Digitization abolishes traditional structures and boundaries. Thus, it is necessary to highlight the digital era's opportunities for society and new fields of activity that have so far been largely ignored.

Digital teaching itself becomes an aspect of teaching: having access to digital equipment is not a matter of course, because there is no fundamental right and universities and educational institutions need to apply for funding. It is about the acquisition of devices such as laptops, tablets, or whiteboards and the integration of these devices into lessons. Not every university is financially that well positioned to have extensive digital teaching equipment and facilities. Here, new challenges require new strategies.

Pure knowledge transfer can succeed very well, if not better than with previous teaching, by fully using digital possibilities. Digitization offers a way to open up the access to education to a larger extent.

The engineering training sets most important basis. It requires an open-minded, interdisciplinary, collaborative mentality of all those involved. The engineer of tomorrow will no longer just plan, construct, maintain a building, but bring people together that are involved in the construction project. The engineer networks knowledge, uses interfaces and interdisciplinary perspectives, shares technical engineering knowledge, leads a project, is part of a large team with a common goal: to use skills and knowledge in a goal-oriented and efficient manner toward a successful, sustainable project. It is about a building that is realized by help of a lot of emerging technologies. The engineer of tomorrow is a visionary, a dedicated one. He tackles work with foresight, works on solutions that are compatible with the common good; the engineer takes a stand on social issues, prevents violations, helps to shape the dynamic field of work preventively, to curb possible negative developments. The engineer promotes an open dialog between the construction and society in order to protect the culture of values in construction industry. His interdisciplinary approach is the most essential requirement. Thus, the curricula need to be thoroughly adapted; the reality of life must be made the subject of engineering training.

Furthermore, from the beginning of studying and training, the engineer needs to work interdisciplinary: with other faculties such as Architecture, Design, Computer Science, Law, Philosophy, Media, and Cultural studies. As the sustainable, value-based design of the living and urban worlds of tomorrow, future-proof urban infrastructures, space, and society are enabled by the necessary ethical principles in dealing with digital technologies and AI, the more technically oriented engineer can supplement his knowledge.

In higher education across the world, the progress of digitization is deeply influenced by government policies and institutional development strategies, both of which play a key role in shaping the digitization landscape of higher education [19].

The following dilemmas require deeper research: Nowadays, university research and teaching have to look for funds and, therefore, choose topics according to demand. Students are confronted with the omnipresent situation of the labor market; lecturers are already part of the academic precariat. The structure and organization of teaching are determined less by a belief in the educational ideal than by the learning of competencies that are intended to increase the individual's chances of competition. Not every excellence strategy and funded chair—often financially supported by companies—means excellent teaching and training. Digitization of teaching hand in hand with a more humane education allows contemporary teaching. Content and structure of academic training require concrete revisions, balancing theory, and practical application with case studies. Transferred to practice this means, e.g., the integration and application of BIM, digital twins, applying simulation methods, getting first contact with AI-based forecasting methods, self-experiencing virtual reality tools. Training personal skills include social, communication skills, network-oriented thinking, critical reflection based on holistic approaches, and interdisciplinary environments.

Digital teaching and training increase the flexibility of study and working hours as much as possible. It demands from each individual a high level of responsible behavior and planning. Such freedom offers high potential: gender-independent access for each and every one.

From November 2019 and February 2021, the author carried out primary studies with expert and interview surveys for winning more information on the recent status of corporate and training policy discussions and implementation of digital technologies and AI, as well as receiving more insights on how companies respond to and handle new needs in terms of specialist knowledge and new job profiles in the digital era. In addition, multipliers were interviewed for interdisciplinary holistic approach—including industry associations and chambers of crafts, foundations, representatives of various specialist disciplines at universities and colleges, educational and teaching institutions.

Fraunhofer Institute IAO and Cyber Valley Stuttgart-Tübingen published the common study with the author [20]. New findings were shared at presentations and conferences with a multidisciplinary, international audience [21]. The reason for choosing the qualitative research method was that the research field is a fringe area, the topic is new, and only the intensive expert interviews offer deep insights into the status and use of technologies, needs, tendencies, critical reflections, social problems, and recommendations for constructive solutions. The evaluation shows a practical implementation of education, knowledge, and awareness building, still bearing a lot of ignorance, business planning performance "on sight," attitude of rejection, and reservations about scientific interdisciplinary work. These conditions that prevent success have to be named. They not only hinder the exchange between specialist disciplines and the search for holistic solutions in the design of the digital transformation process, but also the innovative progress and digital change in construction in

Germany. "*In the technical sciences, it is still a long way off those values and principles are used and that ethics training has to be anchored in training,*" Loh knows [22].

7. Strengthen social and professional skills

Technical experts confirm that progress and reforms in digital change can only be achieved through critical questioning and new food for thought. Responding to corporate responsibility in the digital society requires a new quality of discussion.

The study considers both UN sustainability goals and requirements of the EU Commission in its "*White Paper on AI*" as guide for designing value-based, sustainable digitization and AI. These guidelines offer orientation to strengthen the responsible role of the construction industry. Ethical values and codes of conduct have to be further developed in order to strengthen trust in new technologies. New job profiles tailored to digital competence, automation, robotics, AI and related sustainability issues, are steadily reflected in increasing numbers of start-ups, tailor-made specialist and managerial positions, and new job advertisements. The professional and personal requirements are diverse and extensive (**Tables 2** and **3**).

In addition, new university research initiatives, endowed professorships and chairs are founded, sponsored by industry and companies, and new areas of lesson created. They have in common the formation of technical, interdisciplinary project cooperation—as early as the training phase. For a holistic view, faculties increasingly work cross-disciplines in intercultural teams. Train such forms of cooperation, team structures, processes, and methods from the earliest stage enable to keep pace with technological, economic, and societal changes. The most precious foundation is: reflecting, thinking ahead, and thinking outside the box. Values and ethics, digitization, and AI can no longer only be assigned to other specialist disciplines such as philosophy, law, IT. They must be embedded in the teaching and education of tomorrow's engineers, the engineering sciences.

• Self-learning competence.
• Decision-making ability: In the future, it will be crucial to be able to differentiate between the essential and the insignificant and to be able to assess alternatives.
• Cooperation competence: Engineers should be able to work together, find consensus, and be able to accept each other. In addition to being able to work in a team, this also requires the ability to enter into non-organizational collaborations.
• Cognitive skills.
• Empathy.
• Thinking and acting with foresight, far-sighted leadership.
• Working in partnership with employees, suppliers, and customers (Covid-19 crisis clearly shows: the human factor and good management is the highest selection factor and criterion for quality).
• Think first, then act.
• Creativity.
• Interdisciplinary, network-oriented thinking
• Foreign language opens up for thinking along, empathizing with other people and situations, and empathizing with others.
• Value—and common good—oriented.

Table 2.
Social skills. Source: Bianca Weber-Lewerenz.

• Hybrid competencies: In addition to knowledge and skills of the respective subject area, the engineers of tomorrow also have knowledge of the digital disciplines.
• Interdisciplinary competencies: digital transformation will succeed through interdisciplinary and trans-disciplinary cooperation.
• Simulation technologies: Understanding simulation technologies is the basis for developing systems and scenarios in the digital world.
• Big Data: Engineers know how to obtain information using sensors and how to implement it using actuators. In addition, they should be able to filter large amounts of data and have knowledge of agile process methods in software development.
• Technology assessment: Questions such as data protection and misuse as well as data security and falsification, but also decision parameters of autonomous systems are part of engineering developments. In addition, engineers help shape normative processes.
• Understanding of quality: Engineers must balance well security measures on the software side and the limits of the underlying model approaches.
• Acquisition of skills in the context of digital work and business processes designed as an interdisciplinary cross-sectional task.
• Strategic knowledge and working style
• Intelligent weighing for the use of AI.
• Predictive analytics.
• Safe handling of data, data protection (basic knowledge on legal regulations).
• Being able to explain technologies and thus gain confidence.

Table 3.
Professional skills source: Bianca Weber-Lewerenz.

That is, the Faculty of Applied Computer Science offers a wide range of courses: classic computer science topics and teaching the latest advances in technology. The course is intended to offer future skilled workers a wide range of opportunities on the job market, i.e., to contain potential dangers that arise through the use of digital processes ("Cyber Security") or to develop learning systems ("Artificial Intelligence"). Whether courses such as Applied Computer Science, Business Informatics, or the Internet of Things (IoT), one can choose between countless job offers and be part of shaping digital change. Applied AI, Digital Ethics, Digital Transformation, Digital and Data Science Engineering, Technical Building Automatization, Chief Digital Officer, Digital Ethic Boards, Digital Process Management of Construction Projects, Learning Transport Infrastructure are some of the new job portfolios. In the area of Technical Building Automatization—as part of the climate protection programs—the latest digital methods and AI are applied. In corporate trainings, teaching of hybrid competencies is in full swing.

Daily digital work assumes not only teaching and training digitally but, thus, re-orientation and adaption of qualifications of the teachers. New chances for women arise as to fill in these positions, promote digital innovations, and represent role model for other women. The inclusion of underrepresented and marginalized groups in the design development, and training of the AI systems, and a transdisciplinary approach, involving multidisciplinary and intersectoral partners in the consortium will be essential.

The path of understanding and dealing with AI, understanding opportunities and risks only is paved by an adequate education and rigorous academic training. Education is the core element required to build a legacy of gender equality.

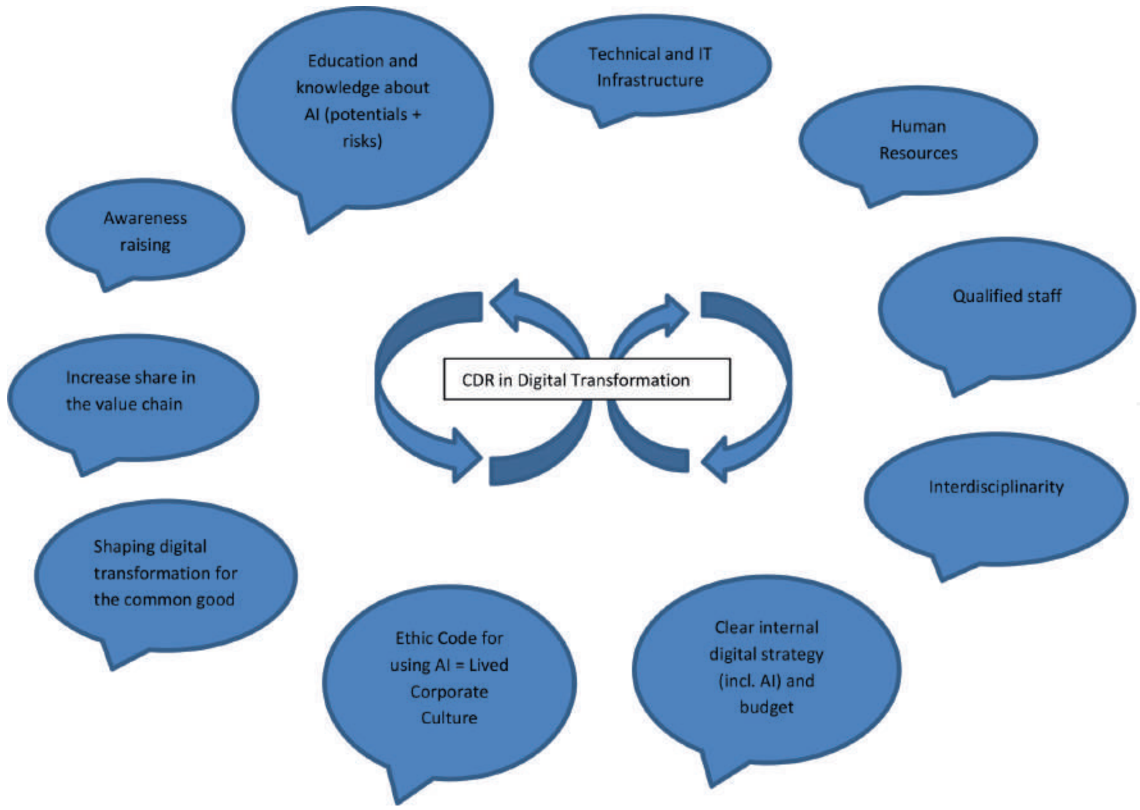

Figure 2.
Mind map "The interrelationship among the key elements of CDR" source: Bianca Weber-Lewerenz.

However, there are several complex issues we need to address. How do we define an optimal "future-proof" curriculum? Who is qualified to teach young children skills that will be beneficial for their future life and careers? How should we deliver this new curriculum? How and should we even score their performance of this revised future-oriented curriculum? The *UNESCO* presented its key findings in the *Global Dialog on AI* and *Gender Equality Report 2020*. The digital era takes diversity, inclusion, and integration into account. What is long overdue must now be pushed faster: adjusted teaching and training regulations, adjusted training and qualification of teachers, creation of new digital learning methods. Innovative, agile university, college, and training locations are in the focus when it comes to the choice of teachers and students determining new work places and study locations.

In times of crisis—such as the corona pandemic—it also became clear who was ahead of the pack when it came to dealing with these tasks. In the digital transformation, they are the key factors for successful implementation in construction (**Figure 2**), which must be sustainably anchored in research, teaching, and training.

8. "German engineering": construction in the focus

New job profiles clearly speak of holistically thinking experts and system-integrating specialists. The learning curve is steep for everyone involved, and the demands in daily construction industry business are equally high: Climate and environmental protection, sustainability with resource efficiency, thinking through the overall construction cycle—from the project idea to dismantling and recycling, keeping within budget and time, as well as realizing the highest quality. New technologies not only ensure but make such processes significantly more efficient, safe, and successful. Teaching and training represent responsible roles for explaining these powerful technological tools and practicing initial approaches. The safe, efficient use of this technology and its effects require targeted instruction in this innovative interaction between human and technology. Why is it important to specifically integrate digital methods and AI into teaching in civil engineering? Because only construction experts are able to localize obstacles and weak points in construction projects, name improvements, and define potential fields of application for digital methods and AI. The sensible use of this technology with the help of an AI strategy tailored to the company and highly qualified staff require a joint rethinking, process and communication improvement, awareness raising with the help of comprehensive education, and orientation through a lot of knowledge. It offers orientation and security for users and employees at all times. Digital growth strategies require digital skills. This is the only way to completely redesign new business models in the construction industry in the digital world of work 4.0. According to experts, the planning and construction industry must redefine itself with reference to its own business models in its own task and job profiles. Close corporate contacts with universities and colleges support the development of professional skills. By communication and technology exchange—via guest lectures and the supervision of bachelor and master theses of students—skilled engineers can be trained. Another perspective is that universities and colleges should be attractive for students and stand out innovatively in the educational landscape. Working in the Construction Industry has lost its attractiveness, maybe it will be possible to revive it with new, exciting technologies?

To women this digital era offers enormous potential in construction in fields of work, research, networking, building trust in new technologies, widen application areas, and set up innovative business models.

In the future, the technical competence increases mutual benefit between young and experienced employees. Because lacking experts in digital technologies and AI, teaching and training make a significant contribution to building on existing skills with the help of additional digital knowledge and to promoting the use of innovation technologies. This increased awareness of the need to create appropriate teaching and lecturing digitization and AI. Following the opinion of university experts, according to interview evaluation, these fields should not just lead to one new field of academic lesson in addition to existing subjects, but be holistically integrated, taught cross-disciplines, and be embedded in all modules and lessons.

In the opinion of economic experts, a general entrepreneurial rethinking and new approaches in corporate recruiting and personnel marketing are required. In terms of strategic personnel planning, companies should define task and job profiles and address them to universities, colleges, and training centers. New job profiles require the integration of new specialist skills.

Universities and colleges should stand out innovatively in the educational landscape when training architects and engineers. Digitization with BIM and AI are opening up new opportunities that could revive the lack of attractiveness of the entire construction industry for years. The use of new technologies and production methods such as the three-dimensional printing of entire components or even houses will be able to counteract the now noticeable shortage of skilled workers.

The Construction Industry has an extraordinarily high reputation: "German engineering" and "German craft ship" stand for the highest quality and sustainability worldwide.

Teaching and training are no longer just training, but to think holistically and in networks, shaping and paving the way for successful digital change.

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9. Conclusion and outlook

There are *four main pillars* of disruptive and transformative change our society needs to undergo as to fully ensure diversity and gender equality: education, profession, culture, and governance. It is important to address all levels of education from preschool to executive level [23, 24]. Furthermore, skills that are expected to be in highest demand in the digital era need to be embedded into the classical curriculum [25].

WEF highlights that some of the top skills in demand by 2025 will be creativity, analytical and innovative thinking, active learning, complex problem-solving, as well as technology design, use, monitoring and control to only, name a few [26].

By offering full access to quality education and equal employment opportunities, societies around the globe ensure to not leave any girl's and women's rights neglected [27].

To be clear: education and training represent the strategic basis for both sustainable digital and human transformation. However, to bring it to the next level, the adaptation of higher education and training will almost certainly need to be accelerated to keep up with the already high dynamics of the digital ecosystem and the emerging technologies. Some of the latest emerging technologies (such as Blockchain, Quantum Computing, Metaverse, AI, IoAI, Next-Generation Computing, 5G and 6G, 3D, IoT, AR, VR and XR etc.) can serve as catalysts or gateways to enhance inclusion and diversity when deployed mindfully [28].

Curricula is far from satisfying the needs of companies and fulfilling the requirements of economy and society. Strategies and white papers are seen too much of theory, there is a gap between the media hype of talking about digital ideas, dreams, and visions, what we can, what we should do, could do, what would be good, what would be great. The gap goes deep right into the daily practice, the practical ways of highly interested companies in implementing such tools and methods, and modern digital working environments, daily routine utilizing digital methods and AI.

Only a minority of universities, universities of applied sciences and schools offer adequate digital infrastructure and learning environment [29]. But innovation requires qualified experts and skilled workforce with diverse and inclusive backgrounds—on both sides: teaching and students. Best practice, user experiences help interested and new users at the start.

How can it be that only a handful of the 100 advertised AI professorships are filled [30], the course content is still not adapted to the requirements of the digital transformation, and companies are desperately facing the shortage of skilled workers, which is still growing?

This research is a direct approach to calls made by the various national and international strategies with focus on the Construction sector—a branch that is being studied scientifically for the first time with this research.

It represents a significant path forward that some Best Practices already walk. For the holistic understanding, algorithm complexity and gender bias are shortly introduced and social and professional skills stressed. Thus, clear definitions of the concrete disruptive changes in curricula can be provided, eventually leading to the German Engineering seal of quality.

This chapter is intended to be a plea for more disruptive thinking and acting in teaching and training. The digital and human transformation begins in the head—where education lays the foundation.

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Conflict of interest

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Publication permission was given by all respondents. Some public statements, which come from internet, literature, and archive research, also underline the quality and statistical values of the expertise and survey values obtained, as well as limitations and urgently necessary measures.

The author of this study conducts external research, is company-independent, and is not financially supported by third-party funds, companies, or other institutions. She is free in her research and shares her findings at the interface of "application practice—applied technical research—economic and social transfer." In this way, the author is researching the responsible use of digitization and AI—neutrally, critically, and inclusive—and promoting the ethical debate about the AI technologies.

Key Terms

AI	Artificial Intelligence is a branch of computer science that deals with the automation of intelligent behavior and machine learning. It is an attempt to reproduce certain decision-making structures in humans, e.g., B. a computer is built and programmed in such a way that it can deal with problems relatively independently. Often, however, it is also used to designate an imitation intelligence, whereby an "intelligent behavior" is to be simulated using mostly simple algorithms.
BIM	Building Information Modeling describes a working method for networked planning, construction, and management of buildings and other structures using software. All relevant building data are digitally modeled, combined, and recorded.
Diversity	Diversity is the range of human differences, including but not limited to race, ethnicity, gender, gender identity, sexual orientation, age, social class, physical ability or attributes, religious or ethical values system, national origin, and political beliefs. Diversity of people does not mean just the obvious in terms of demographics such as race, ethnicity, gender, and age. Diversity means people

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	with different skill sets, experiences, educational backgrounds, cultural and geographic perspectives, ways of thinking and working. Diversity is part of social, corporate, and political responsibility.
STEMs	These fields include Science, Technology, Engineering, and Mathematics.

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Chapter

Virtual Internet of Things Laboratory Using Node-RED

Kalapatapu Venkata Sai Krishna Raja Shiva Kumar, Attaphongse Taparugssanagorn and Arunya Prasantha Senadeera Senadiri Dumunnage

Abstract

Due to the pandemic or any other tough situations, attending the student laboratory session physically is difficult or even impossible. To overcome this problem, a virtual laboratory can be introduced. In many universities, virtual teaching methodology is not implemented widely. While there are several existing visual programming languages developed for various applications, an open-source visual programming language named Node-RED, which is particularly used for Internet of Things (IoT)-based applications, is taken into consideration in the book chapter. A complete outlook of Node-RED, which can be applied for an IoT-based virtual laboratory, is described. Its simplicity providing many built-in entities makes it possible to evolve innovative platforms with less coding complexity. The configuration, the flow development, the requirements, and the usage of the Node-RED are explained with respect to handling all the various types of errors. A few experimental cloud-based services are implemented on an IoT platform using serial port and message queuing telemetry transport (MQTT) broker service as well as providing live camera capturing feature with artificial-intelligence-based object detection. The results show that real-time IoT sensor data can be efficiently measured and visualized in dashboard and live object detection can be done with good accuracy.

Keywords: node-RED, visual programming language, open-source, Arduino MQTT, amazon cloud

1. Introduction

In this modern era, there has been a lot of development and upgradation in the field of Internet of things (IoT). The development has been actively growing in various sectors, for instance, industries, healthcare, education, agriculture, just to name a few. Consequently, it creates more employment opportunities. Thus, IoT should come into intensive usages with very careful awareness. The development of IoT programs can be done in various ways into the society. Although there have been a plenty of IoT development and applications, only very few academic institutions throughout the world are fully IoT equipped in their laboratories.

Since 2019, the COVID-19 pandemic has resulted in shutdown of educational institutions across the world. Globally, over 1 billion children are out of the classroom. As a result, education has changed dramatically with the distinctive rise of e-learning, whereby teaching is undertaken remotely and on digital platforms. While lecture sessions have been quite well organized, the laboratory sessions might be still challenging and dependent on the types of laboratories. To overcome this problem for an IoT design class, a virtual laboratory can be implemented. With a virtual laboratory, a laboratory session can be launched with flexibility of time. Self-learning process can be achieved by becoming more self-determining. It also supports collaborative group works and helps us develop critical thinking skills while doing individual assignments. The most important advantage is that it can be accessed from any location through Internet. Thus, any materials from the Internet can also be used. Nevertheless, there are some challenges in the virtual laboratory, which includes setting up the virtual laboratory environment, lack of social interaction between students and instructors, accessibility to various laboratory required technologies, software requirement and software inconsistency, student's issues while teaching simultaneously, etc. A visual programming language (VPL) is any programming language that lets users create programs by manipulating program elements graphically rather than by specifying them textually. A VPL allows programming with visual expressions, spatial arrangements of text and graphic symbols used either as elements of syntax or secondary notation. Many VPLs known as dataflow programming are based on the idea of boxes and arrows, where boxes or screen objects are treated as entities connected by arrows, lines, or arcs representing relations. Different prototyping boards have its own programming language, such as C, Python, Java, and similar. To develop an IoT system, at least one of these programming languages is required. However, it is fortunate that during these days, several VPLs have been developed to help us start programming without knowing the programming language. These IoT visual programming tools have a user-friendly approach of programming. It has a graphical user interface (GUI), where the user can just drag and drop moving code blocks and execute a simple piece of logic.

Node-RED VPL is an open-source software, which is a flow-based development tool originally developed by International Business Machines (IBM) for wiring hardware devices together with application programming interface (API) and few online services as part of the IoT. Node-RED can be used flexibly under the Apache2 license. Some developed their own services based on Node-RED, while others changed to their own user interface (UI) and deployed it as built-in. It can be established as a platform where we can publish our own developed node so that anyone can use it. The open-source software is an alternative to interact with the class. Students can practice, study, and understand with basic engineering skills or even develop an IoT-based system with artificial intelligence (AI) capabilities, e.g., prediction, regression, clustering, and classification. It can be installed locally on a personal computer (PC) or a laptop. With its simplicity for learning and using as well as several built-in entities, it can be used in evolving innovative platforms providing ability to assign code to all interfaces with less coding complexity. In addition, it supports several IoT prototyping board such as Arduino, Raspberry, and Android as well as cloud-based platforms.

The objectives of the book chapter are as follows.

- To describe the environment and features of Node-RED software with its abilities of numerous functions.

- To deliver a complete outlook on each function of Node-RED that can be applied for an IoT-based virtual laboratory.
- To talk over the suitability and rightness of machine learning and deep learning centered explanations in numerous practical fields.
- To arrange for a broad opinion on machine learning algorithms, which can be put to build-up the abilities of a data-driven approach.
- To highlight and summarize the possible study for smart systems including cloud technology.
- To bring out the virtual awareness/importance of IoT including laboratory sessions.

The rest of the book chapter is organized as follows. Section 2 presents the past related existing works on VPL and NodeRED. In Section 3, the step-by-step methodology of the work is described in detail, which includes getting started, configuration, utilization, and machine learning (ML) package for Node-RED. The experimentational examples are provided along with the corresponding results in Section 4. Section 5 discusses about the results. Lastly, the conclusion is drawn in Section 6.

2. Related work

IoT has been playing an important role throughout the globe. It is a combination of both software and hardware tools. With the support of VPL, IoT can be applied into our day-to-day essential things. According to the survey by Ray in 2017, there were 13 VPLs for the usage and for the upgradation of IoT [1]. The VPL is classified into two types, namely open-source and proprietary-source with the four following main features, i.e., programming atmosphere, license, project source, and platform support [1]. Students can use open-source VPL such as Node-RED to learn and implement an IoT system or device with basic engineering skills and low-code programming. It helped many programmers to develop new software [2, 3]. Node-RED was initiated and was developed by IBM for connecting hardware devices with web-based editors [2, 3]. It was then applied further in the field of IoT. Rajalakshmi and Shahnasser came with a problem while making a cloud-system for IoT devices [4]. This is difficult to update the firmware by reinstalling the devices. To solve this issue, Node-RED was used without reinstalling the device and changing the programming code with quick setup [4]. In 2018, a model based on LoPy, which is a MicroPython triple-network development platform doubling up as a long-range (LoRa) Nano gateway, was connected to a system that uses Node-RED for interfacing with a local actuator and the external data with protocols [5, 6]. Their IoT development could be done in fog/clouds. The introduction of the IoT in education allows Internet-based communications to occur between things, sensors, and actuators. This has improved educational institutions [7–14]. In 2015, Giang et al. implemented a distributed Node-RED (D-NR) framework for building various types of IoT applications, which can work efficiently with simple designing process and less time [15]. Abdel-Basset et al. could make an efficient framework by new ideas with lower cost and greater security [16].

The advantages in maximizing IoT became more for the institutions, i.e., bringing out an affluent knowledge, better quality of working efficiency, and gaining real-time experiences [17]. In addition, they could keep track record of all the university resources with secured data accessibility. Using an open-source platform such as Node-RED, it helps for the creation of new ideas, i.e., linking up with many other specialized courses, for instance, information and communication technologies (ICTs), embedded system design, humanities, agricultural, just to name a few, yielding a good IoT program of study for students to learn and make research [16]. Another model was proposed by Marquez et al. as an IoT educational platform for virtual academic communities [17]. In 2020, Torres et al. used VPL with Node-RED to improve their IoT system by reducing the time taken for the development, i.e., reducing the number of failed attempts while deploying an IoT system [18]. Home automation consisting of water heater, cooling systems, electrical outlets was raised all over the IoT using cloud-platform where Node-RED is used to make fast setup for remote monitoring and control of data with a mutual communication [19]. In 2021, David et al. worked on indoor crop agriculture by monitoring parameters such as humidity, temperature, and light intensity with the help of IBM-Bluemix, which is the IBM open cloud platform providing mobile and web developers access to IBM software for integration security transaction and other key functions [20]. The data was transformed into Node-RED platform through a mobile application for tracking purpose of the farmers. Thuluva et al. made a solution for interoperability problem for IoT semantic web technologies in industrial field using semantic Node-RED models with feasibility and scalability approach [21]. A rapid and low-cost IoT prototype was developed by Ferencz and Domokos within less time on Node-RED using the combination of various cycle power plant dataset [22]. A low-power wide area network (LPWAN) technology called LoRa with its medium access control (MAC) layer protocol called LoRaWAN was deployed by Fox et al. in 2019, and these end devices interact with a gateway using Node-RED connection to an IBM-IoT platform [23]. Node-RED was applied and analyzed by Olsson and Eric in terms of modeling and security with misuse of API and providing security guarantees [24]. Clerissi et al. made a model for testing and developing IoT platforms using Node-RED with the functional behavior and the static view of the system. The class diagrams were used by testing, defining, and generating in java script using a Mocha test framework [25]. Proper regulations and rules for all the Node-RED developers were given by Clerissi et al. [26]. They are about the comprehensibility issues, which can be used to increase efficiency by reducing errors and time to complete tasks.

VPL is any programming language that lets users create program by manipulating program elements graphically rather than by specifying them textually [27, 28]. A VPL allows programming with visual expressions, spatial arrangements of text and graphic symbols used either as elements of syntax or secondary notation. For instance, many VPLs known as dataflow or diagrammatic programming are based on the idea of "boxes and arrows," where boxes or other screen objects are treated as entities, connected by arrows, lines, or arcs representing relations [29–31]. There are several different VPLs, which can be divided into different fields of applications, such as education (23 languages), multimedia (26 languages), video games (18 languages), systems (34 languages), automation (4 languages), data warehousing (8 languages), legacy (5 languages), and miscellaneous (10 languages) [29–31]. The difference between a regular programming and visual programming, in terms of type, nature, flexibility, speed, efficiency, interface, learning complication, space usage, and example, is shown in **Table 1**.

No	Context	Regular programming	Visual programming
1	Type	Use only text	Use only graphics
2	Nature	Not user-friendly	User-friendly
3	Customizable	Very high	Moderate
4	Flexibility	High	Low
5	Speed	Very high	Low
6	Efficiency	Very high	Moderate
7	Interface	Not good	Great
8	Learning Complication	Take time	Easy to learn
9	Space Usage	Less	High
10	Example	Python, Java, etc.	Drakon, Helix, etc.

Table 1.
Difference between regular programming and visual programming.

Node-RED is preinstalled in many devices, such as Raspberry Pi, Intel, Fujitsu, just to name a few. Moreover, there are several different cloud services including Cisco, Nokia, IBM, Hitachi, etc., using Node-RED as a VPL and a dataflow programming.

3. Methodology

This section describes the complete scenario of methodology process. As can be seen in **Figure 1**, the first stage is installation, which involves the three following types, i.e., local machine, Raspberry Pi, and cloud services. After the correct installation, the Node-RED is configured involving all the basic nodes required to make a workflow with deployment activities. Next, the utilization is the main stage in which the development of the flows, handling errors of all the core nodes are explained. Accordingly, when the utilization process is completed, any type of experiments can be implemented with the expected and accurate outcomes.

3.1 Getting started

Getting started by installing Node-RED can be done on various criteria, which are explained as follows.

1. Running on a local machine for Windows 7 and above

   Windows 7 and above versions have the capability of installing Node.js, Node-RED, and node package manager (npm) using command prompt (cmd) or Powershell. The procedure is described as follows.

   - Node.js (version 14.x long term support (LTS) or above) is installed.

   - All the local administrators are given their rights.

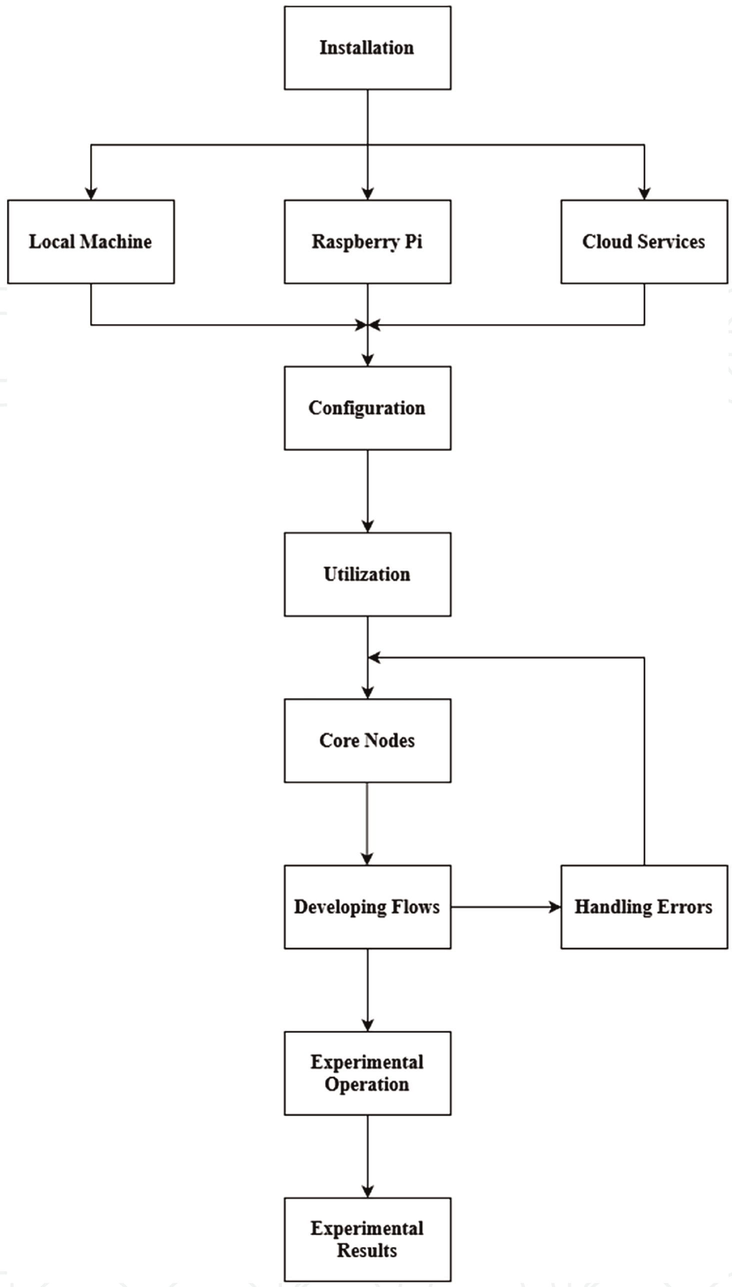

Figure 1.
Block diagram representing methodology workflow.

- Cmd or Powershell is opened and the following code is run to check if it is installed correctly or not installed.
- "node –version; npm –version" (Powershell),
- "node –version && npm –version" (cmd)
- Node-RED is installed by the command "npm install -g –unsafe-perm node-red."
- As soon as installed, the cmd and type "node-red" is opened. As an output, a terminal log of Node-RED is displayed on the screen.

2. Running on a Raspberry Pi or any other IoT module

   Buster is the supported version for Node-RED at present for all the Raspberry Pi Operating Systems (OS).

   - The subsequent command is used to install node.js, npm and node-red on any Raspberry Pi.

   "bash < (curl-sLhttps://raw.githubusercontent.com/node-red/linuxinstallers/master/deb/update-nodejs-and-nodered)".

   (This command is used on any Debian-based OS like Ubuntu, DietPI.)

   "bash < (curl-sLhttps://raw.githubusercontent.com/node-red/linux-installers/master/rpm/update-nodejs-and-nodered)".

   (This command is used on any Red-Hat packet management (RPM) based OS like Red Hat, Fedora, CentOS, Oracle Linux.)

3. Running on different cloud services (IBM cloud, Amazon web services, Microsoft Azure)

   Node-RED is used on different cloud-based services with many features depending on the user or the client requirements.

   - For International Business Marketing (IBM) cloud: It is highly virtualized with high power, storage, networking, security, data management, analytics, developer tools, IoT, and integration and migration of virtual servers.

   - For Microsoft Azure: It is also having the same abilities like IBM cloud with some extra added features such as replacing as an supplement for many other on-premise virtual servers with best recovery support.

   - For Amazon web services (AWS): It has various new features when compared with many other cloud-services for developing new innovative smart devices, where it includes all the required API with less cost for the third-party usage.

3.2 Configuration

This section describes about various types of configurations that are needed for the deployment of each different application with default parameters in the default file directory.

- Normal application: Entire structure is loaded by default settings file, which is a built-in source.

- Embedded application: It is passed into property called RED.init(), where embedded.

- Run-time configuration: It defines the time-value of each node during the deployment.

- Logging configuration: Only console logging is supported in Node-RED.
- Node configuration: It is in the hierarchical format used for the application deployment.
- External module configuration: It defines about the run-time handling external npm modules and decides whether the editor allows new node modules to be installed such as the function node to have their own dynamic configured dependencies.
- Editor configuration: It is a set of files with different coding styles with various text editor plugins.

    1. adminAuth: It permits security for user in the editor and admin API.
    2. paletteCategories: It describes the sequence of types in the palette. By default, the pattern is subflow, common, function, network, sequence, parser, storage.

The run-time configuration is explained as follows.

- Flow file: It is used to store the flows.
- Userdir: It is used to store user data, credentials, and library data.
- Nodesdir: It is used to search additional installed nodes.
- Uihost: It is an interface to listen all connection on IPv4.
- Uiport: It is a port to serve ui editor.
- Httpadminroot: It is the root url, which contains both API and editor UI.
- httpAdminAuth: It allows HTTP validation on the editor UI.
- httpAdminMiddleware: It is an array of all functions, which is added to all admin routes.
- httpNodeRoot: It is the node root for all the urls that run HTTP at all endpoints.
- httpNodeAuth: It enables HTTP Basic Authentication
- httpRoot: It enables the root url to run on both admin and node endpoints through overriding httpAdminRoot and httpNodeRoot value.
- https: It permits https.
- httpStaticAuth: It supports basic confirmation and validation of HTTP with the static content.

- httpNodeCors: It is source distribution for the nodes, which are responsible for HTTP endpoints with cross-origin authentication.

- httpNodeMiddleware: It permits custom processing. For example, validation is required for the node.

Various stages of logging configuration used in Node-RED are described as follows.

- Fatal: Errors that make application unworkable are tracked.

- Error: Tracked errors for requests and fatal errors.

- Warn: Record of the problems about non-fatal and fatal errors.

- Info: Tracked information of application, warnings, error, and fatal errors.

- Debugging (Debug): Tracked information, which is more verbose than information, warnings, error, and fatal errors.

- Tracing (Trace): Tracks about all complete logging, debugging, info, warnings, error, and fatal errors.

The node configuration is explained as follows.

- Function Node: It is for gathering bits and pieces to attach into universal functions.

- functionExternalModules: It allows adding additional modules that are available to the function.

- Debug Node: Any message directed to the debug sidebar tab with maximum size and characters.

- MQTT Nodes: If the link is misplaced, how much time to pause in milliseconds before trying to connect.

- Serial Nodes: How much time to pause in milliseconds before making an effort to revive into serial port

- socketReconnectTime: How much time to pause in milliseconds before trying to connect again.

- socketTimeout: How much time to pause in milliseconds before scheduling out any port.

3.3 Utilization

3.3.1 Core nodes

The important nodes used for the basic functioning of the Node-RED are called “core nodes.” The main six types of core nodes are explained as follows.

1. Inject: It starts any flow manually by clicking the inject button. It can be at required intervals or any time within the editor.

2. Debug: It is used to show messages in the Debug sidebar in the editor, and the control on the node can be used to permit or restrict its outcome.

3. Function: It permits JavaScript code to run beside the messages delivered from it.

4. Change: It is used to transform message properties and fix context properties without changing a Function node with multiple operations such as set, change, move, delete.

5. Switch: It permits messages to be routed into different divisions of a flow by means of calculating set of instructions compared with each message with rules values, sequence, expression, otherwise property.

6. Template: It is used to produce text by message properties to fill the template.

3.3.2 Developing flows

It is the section in which all the necessary placement and arrangement of the nodes are done for the successful execution on the Node-RED.

1. Flow structure: It helps us organize flows, approaches for splitting into smaller, reusable components, and how to modify them to make use in different platforms.

2. Message design: It helps how to design messages to create nodes and flows, which can work together with any number of nodes and are easier to maintain.

3. Documenting flows: It helps about making or providing documentation on what tools and techniques Node-RED provides.

3.3.3 Handling errors

It is described as tracing out the bug or an error, which helps to reduce the developing time and correct the errors easily. The different types of errors on Node-RED are explained as follows.

1. Logging error: It displays the error with the date and time of the error and the node, which is noted as an error.

2. Catchable error: It will not be logged, but it informs about run-time error. Then, the Catch node will be used to produce a flow which can handle it.

3. Sub-flow error: It will not be logged but it informs about run-time error. Then, the Catch node will be used to produce a flow, which can handle it.

4. Uncatchable errors: If the error is written in the log, then a message is seen in the Debug sidebar and log outcome. But creation of a flow is not possible to handle it.

5. Uncaught errors: It causes the Node-RED run-time to shut down and cannot be controlled in the flow as they are produced by bugs in nodes.

6. Status changing errors: It is used to control modifications in node position by including the position property which provides the data about the position with the node that caused the incident.

3.4 Machine learning (ML) package for node-RED

This node-red-contrib-machine learning module for Node-RED contains a set of nodes offering machine learning functionalities. Such nodes have a python core that takes advantage of common ML libraries such as SciKit-Learn and Tenserflow. Classification and outlier detection can be performed using this package.

3.4.1 Usage

These flows create a dataset, train a model, and then evaluate it. Models, after training, can be used in real scenarios to make predictions.

Flows and test datasets are available in the "test" folder. We need to make sure that the paths specified inside nodes' configurations are correct before trying to execute the program. "node-red" can be run from the folder ".node-red/node-modules/node-red-contrib-machine-learning" and the paths will be automatically correct. The flow shown in **Figure 2** loads a csv file, shuffles it, and creates a training and a test partition.

The flow shown in **Figure 3** loads a training partition and trains a "decision tree classifier" and then saves the model locally.

The flow shown in **Figure 4** loads a test partition and evaluates a previously trained model.

Figure 5 shows the flow of how to use a trained model during deployment. Data is received via mqtt, predictions are made and then sent back.

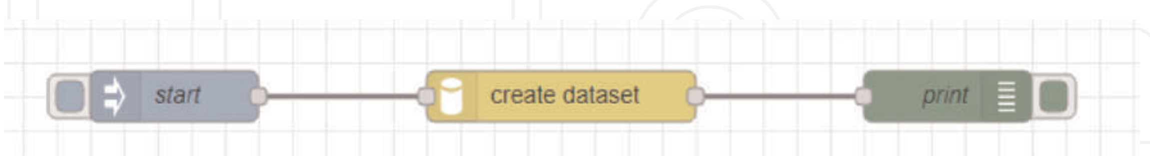

Figure 2.
Flow for loading a csv file, shuffling it, and creating a training and a test partition.

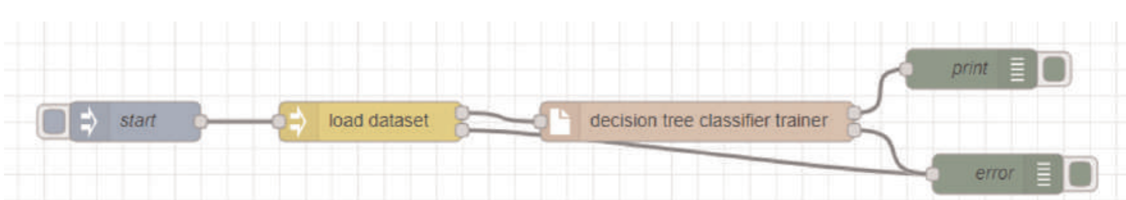

Figure 3.
Flow for loading a training partition and training a "decision tree classifier".

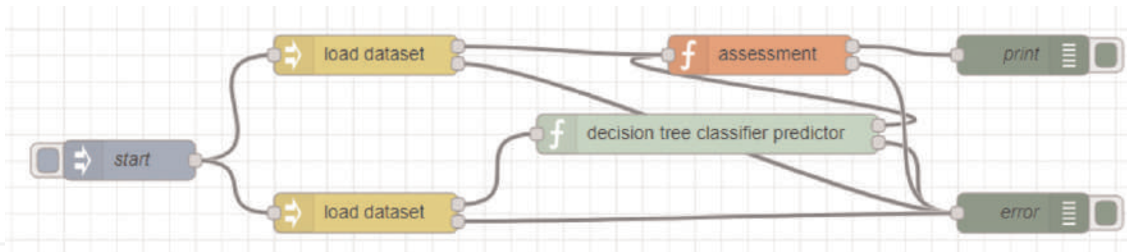

Figure 4.
Flow for loading a test partition and evaluating a trained model.

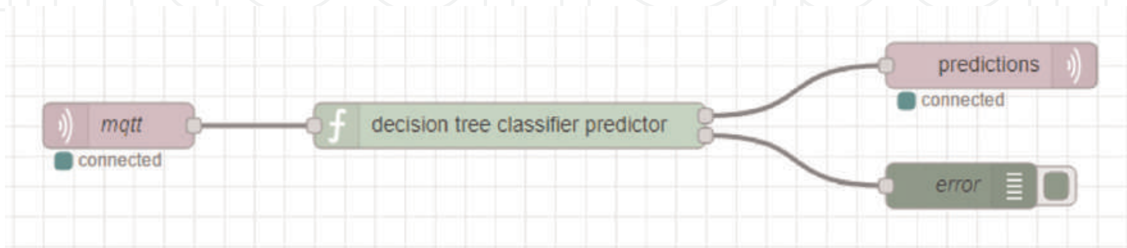

Figure 5.
Flow for showing how to use a trained model during deployment.

4. Experimentation

In this section, various types of experiments related to IoT are provided. ESP32, which is a microcontroller chip manufactured by Espressif Systems, is applied. It consists of a low-cost and a low-power chip with features such as Wi-Fi (IEEE802. 11 b/g/n), Bluetooth, and built-in antenna. The distributed hash table (DHT11) is a basic, ultralow-cost digital temperature and humidity sensor. It uses a capacitive humidity sensor and a thermistor to measure the surrounding air and spits out a digital signal (using an 8-bit microcontroller unit (MCU)) on the data pin. An Arduino integrated development environment (IDE) is used to write and upload programs to the Arduino compatible boards supporting the languages C and C++. Message queuing telemetry transport (MQTT), which is a lightweight messaging protocol, is used on such a small microcontroller that allows messaging between device to cloud and cloud to device with supporting several IoT devices. By using MQTT commands can be sent to control outputs, data can be read and published from sensors. Therefore, communications between multiple devices can be established. We can send a command with a client to control outputs, or we can read data from a sensor and publish it to a client.

4.1 Experimental examples

Example 4.1.1 DHT11 Sensor Data on Node-RED using a Serial Port (ESP32).
The procedure of this task is described as follows.

1. The ESP32 is connected to the DHT11 sensor as shown in **Figure 6** (GND TO GND, 3.3 V TO VCC, GPIO4 TO DATA PIN).

2. If the connections are correct, then a light present on the DHT11 sensor is turned on.

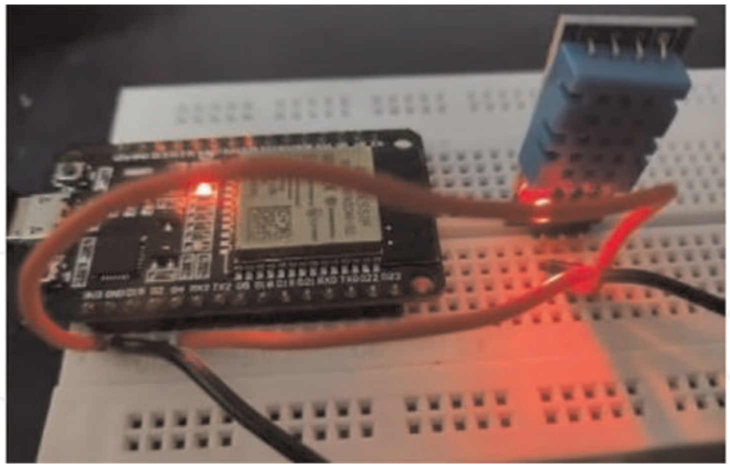

Figure 6.
ESP32 connection with DHT11 temperature sensor (serial port).

3. The DHT11 sensor is programmed into the Arduino integrated development environment (IDE) and uploaded into the ESP32 to show the corresponding temperature and humidity.

4. If the required packages are absent, then the Arduino IDE shows an error while uploading the code.

5. After the code is successfully uploaded, we can click on the serial monitor to see the corresponding temperature and humidity readings of the DHT11 sensor.

6. The Node-RED software is installed into the system. Then, the local hosting address of the Node-RED is open. This can be run on any browsers.

7. The required nodes, i.e., dashboard and serial port, are installed.

8. A flow is created as shown in **Figure 7**.

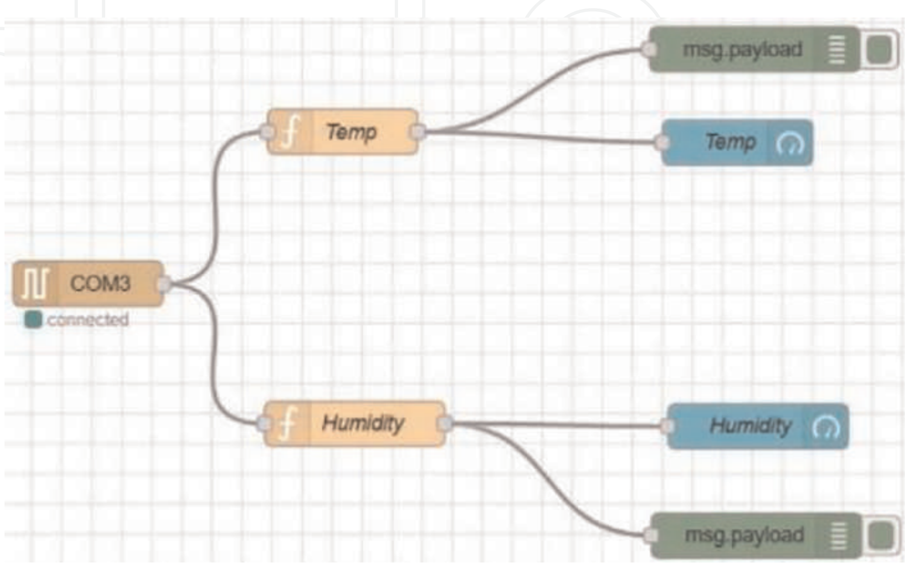

Figure 7.
Node-RED serial port connection for temperature and humidity.

9. A serial is inserted into the port node, one function node for temperature and another function node for humidity, which display the DHT11 sensor data.

10. To get the representation, two-gauge nodes for temperature and humidity are inserted and connected to their respective function nodes.

11. Finally, the overall workflow is deployed.

Example 4.1.2 MQTT Broker Service (ESP32) on Node-RED with DHT11 Sensor Data. The procedure of this task is described as follows.

1. The ESP32 is connected to the DHT11 sensor as shown in **Figure 8** (GND TO GND, 3.3 V TO VCC, GPIO4 TO DATA PIN).

2. If the connections are correct, then a light present on the DHT11 sensor will be turned on.

3. The DHT11 sensor is programmed into the Arduino (IDE) and uploaded into the ESP32 to show the temperature and humidity.

4. If the required packages are absent, then the Arduino IDE shows an error while uploading the code.

5. After the code is successfully uploaded, click on the serial monitor to see the temperature and humidity readings of the DHT11 sensor.

6. The Node-RED software is installed into the system. Then, the local hosting address of the Node-RED is open. This can be run on any browsers.

7. The required nodes, i.e., dashboard, MQTT-in, and MQTT-out nodes, are installed.

8. A flow is created as shown in **Figure 9**.

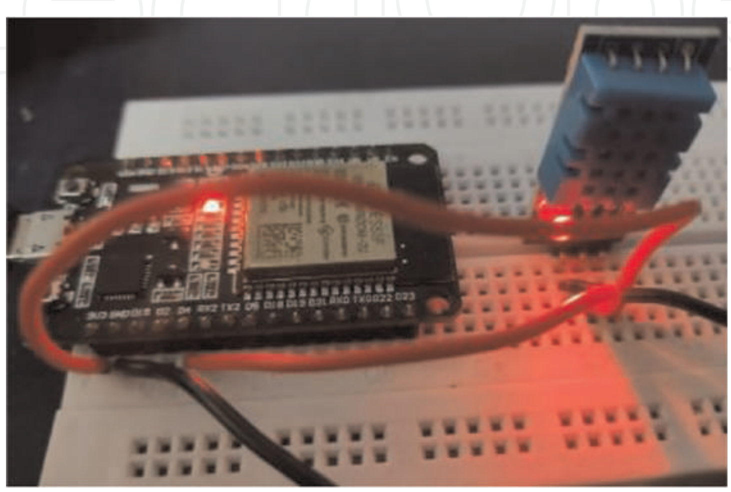

Figure 8.
ESP32 and DHT11 temperature sensor (MQTT broker service).

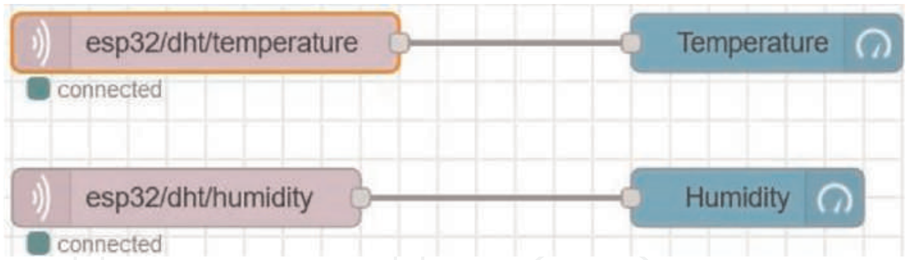

Figure 9.
MQTT broker service for temperature and humidity with node-RED.

9. Two MQTT-in nodes, one for temperature and another for humidity, are inserted.

10. This extracts the sensor data from the ESP32 through the MQTT broker service and gets into the Node-RED platform with the help of the local-host ip address.

11. To display this data, the one gauge is connected to the temperature node and the other is connected to the humidity node.

12. Finally, the overall workflow is deployed.

Example 4.1.3 Live Camera Capture and Object Detection using Machine Learning (ML).

In this example, a user interface (UI) has a major role for making an interface between the user and the Node-RED dashboard by the means of a system camera and a UI-table. **Figure 10** shows the procedure of this task, which is described as follows.

1. The Node-RED software is installed into the system. The local hosting address of the Node-RED is opened. This can be run on any browser.

2. The required nodes, i.e., random, dashboard, UI-table, UI-webcam, tfjs-coco-ssd, tf-model, tfjs-node (tf = tensorflow), are installed.

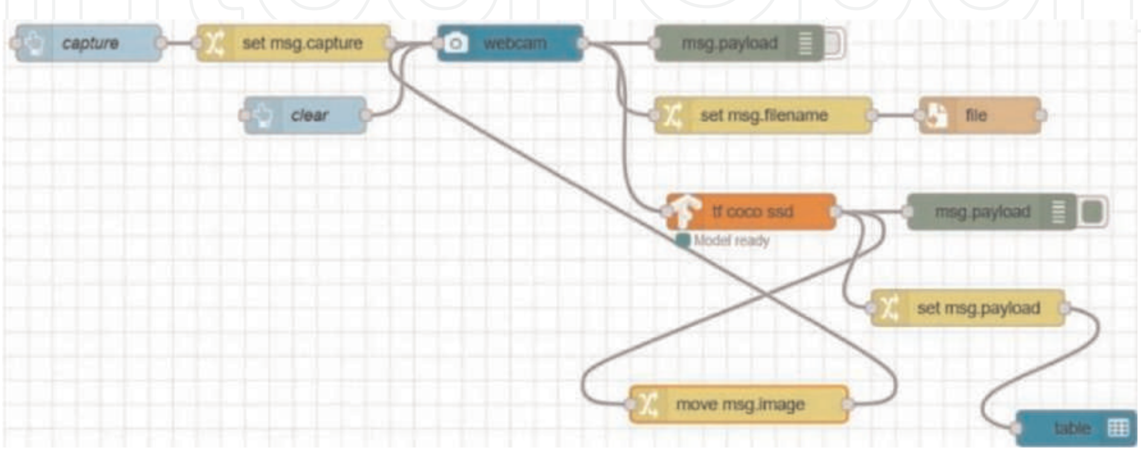

Figure 10.
Node-RED flow for live camera capture and object detection using machine learning (ML).

3. We connect the nodes by inserting button node = 2 (capture and clear), change node = 4 (set msg.capture, set msg.filename, set msg.image, set msg.payload), UI-webcam node = 1, UI-table node = 1, tfjs-coco-ssd = 1, debug node = 2 (msg. payload), file node = 1.

4. We check whether the camera of the PC/laptop is working or not.

5. After deploying successfully, we go to the hosting ip address followed by /ui, which opens another new webpage showing the output of the live web camera.

The object detection flow recognizes objects in an image and annotates objects with bounding boxes. An image can be loaded from a built-in camera, the file system, or by injecting the default image. We need to make sure that we have the node-red-contrib-browser-utils package installed for all these input nodes to work. This flow uses three of the custom nodes mentioned above (tf-function, tf-model, and post-object-detection). The loaded image is passed into the preprocessing node as msg.payload. The msg object is a JavaScript object that is used to carry messages between nodes. By convention, it has a payload property containing the output of the previous node. The preprocessing function node is an example of tf-function that directly calls the tf.node.decodeImage method with the predefined tf variable. The node produces a Tensor4D image representation as the payload and then passes it to the COCO SSD lite node, which is an instance of the tf-model custom node. This loads the COCO-SSD lite model.json from an external URL and runs inference on the model.

The result of the model goes through the postprocess node that returns an object array containing bbox, className, and score properties. The objects node combines an additional property, complete that is set to true, to the msg with the image object. Then, the bounding-box node draws bounding boxes on the input image and displays it in the browser.

4.2 Experimental results

Example 4.2.1 DHT11 Sensor Data on Node-RED using a Serial Port (ESP32).

Once after the successful deployment, we go to the hosting ip address followed by:1880/ui, which opens another new webpage representing the gauge readings of the temperature and the humidity of the DHT11 sensor. The temperature and humidity readings are directly sent from the serial port to the Node-RED directly. **Figure 11**

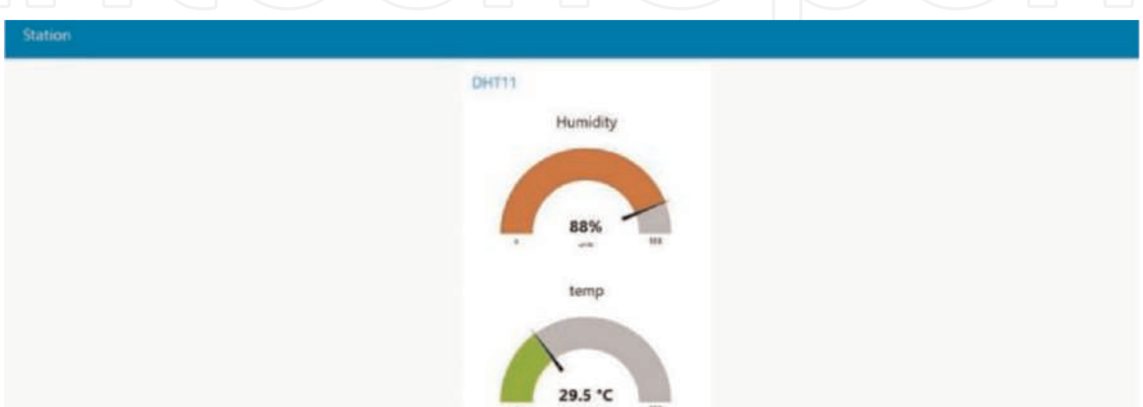

Figure 11.
Dashboard of temperature and humidity from DHT11 sensor (serial port).

shows an example of the dashboard showing temperature and humidity from the DHT11 sensor (serial port).

Example 4.2.2 MQTT Broker Service (ESP32) on Node-RED with DHT11 Sensor Data.

Once after the successful deployment, go to the hosting ip address followed by:1880/ui, which opens another new webpage representing the gauge readings of the temperature and the humidity of the DHT11 sensor. Temperature and humidity readings are sent from the sensor to MQTT broker (as a cloud), then finally sent to the Node-RED as a third-party service. **Figure 12** shows an example of the dashboard showing temperature and humidity from the DHT11 sensor (MQTT broker service).

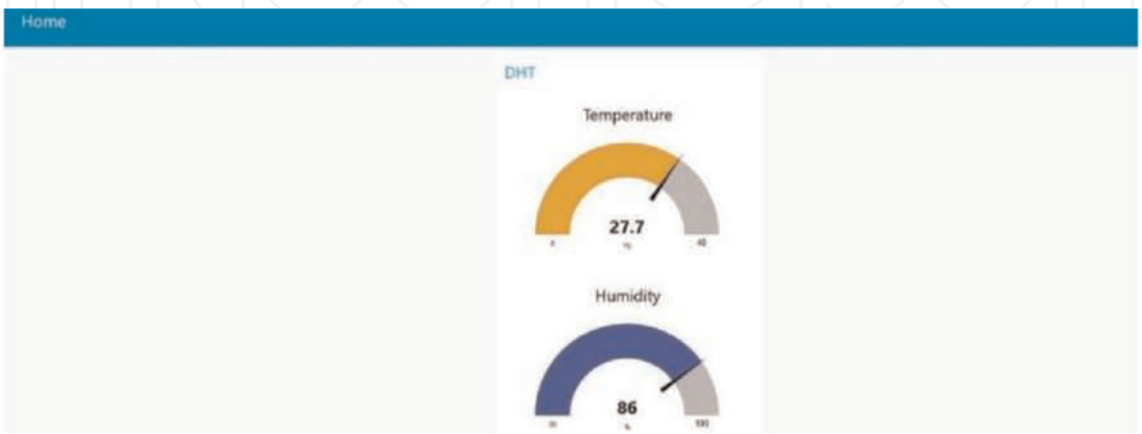

Figure 12.
Dashboard of temperature and humidity from DHT11 sensor (MQTT broker service).

Example 4.2.3 Live Camera Capture and Object Detection.

When the deployment is successful, go to the hosting ip address followed by:1880/ui, which opens another new webpage asking for the permission to allow camera

Figure 13.
Debug message showing single object class and accuracy score.

Figure 14.
Debug message showing dual object class and accuracy score.

(Press allow). Then, we can see the live camera working and press the capture button to capture. It detects the object with the help of TensorFlow analysis node as earlier describe and the output can be seen on the debug panel with the accuracy score of its correctness. The examples of the single object and the dual object detection are shown in **Figures 13** and **14**, respectively.

4.3 Implementing as a mobile application

From the given examples, they can also be made visible on a mobile phone for both iOS and Android. It is done through remote access just by installing the application named "RemoteRED" from the mobile app store. The steps are explained as follows.

1. Install the Remote-RED node in the Node-Red.

2. Open the Remote-RED settings and configure it to get the QR code.

3. Open the Remote-RED application from the mobile phone and scan the QR code.

4. Wait for a minute as it is asynchronous to get updated on the mobile phone.

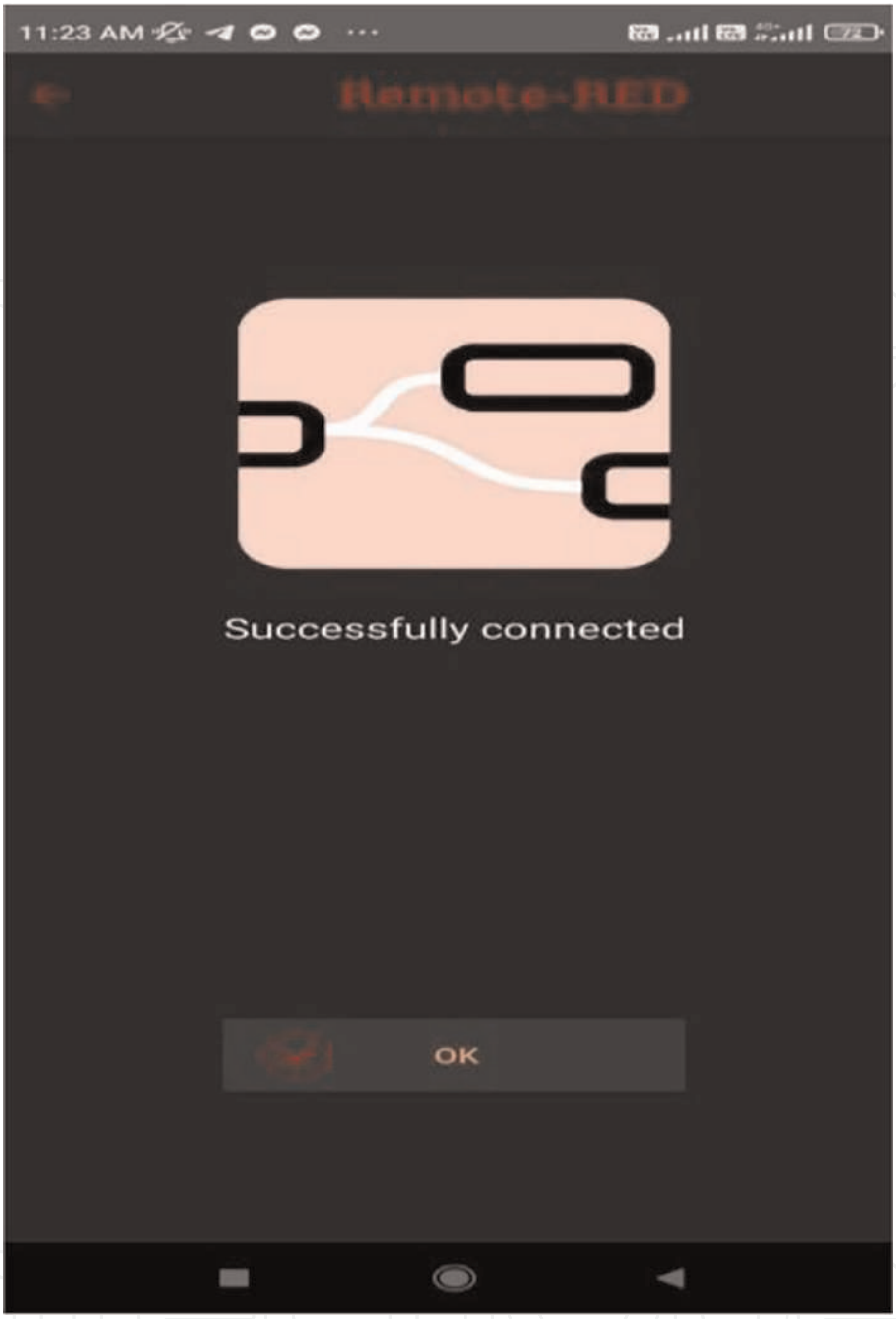

Figure 15.
Connecting to remote-RED application (iOS/android).

5. Now we can see the same output of the Node-RED on the mobile phone Remote-RED application as shown in **Figure 15**.

6. This process is the same and it works for any Node-RED workflow.

5. Discussion

The results show that simulated systems developed using the Node-RED can be deployed in the real world without changing the system parameters. Moreover, the simulated system can be connected with hardware platforms easily. VPL-based hands-on tools are effectively smoothing the beginner's learning curve on IoT. The stranded network protocols and IoT protocols are easy to understand using hands-on experience and deploy in the Node-RED environment. Node-RED system models are easy to debug compared with the traditional programming debug methods. The platform works well in both Internet and Intranet mode as all the components are virtually presented in Node-RED. After all, the laboratory instructors can effectively convey the basics of network and IoT concepts to the students through a VPL language including the Node-RED.

6. Conclusion

The book chapter described a complete outlook of Node-RED that can be applied for an IoT based virtual laboratory. The configuration, the flow development, the requirements, and the usage of the Node-RED were explained with respect to handling all the various types of errors. We modeled, implemented, and tested the IoT virtual laboratory using Node-RED. The implemented virtual laboratory system is currently serving for flexible postgraduate programs and broadcasting completely online. Students obtain great encouragement and motivation toward virtual IoT hands-on practices as they can manage their own and convenient time and a location. The virtual laboratory concept utilizes the available hardware (Wi-Fi IEEE802. 11 b/g/n routers, classical Bluetooth hardware, and system-on-chip (SoC) like MCU) at the student location. The virtual IoT laboratory concept was proved to help students to learn faster than a classical theory class or a video-recorded lesson. With the simplicity of Node-RED and its built-in entities a few examples, which can be used for an IoT-based virtual laboratory, were done to evolve innovative platforms with less coding complexity. It provides flexibility such that the remote laboratory can run on several operating systems or on a mobile application. The proposed solution is platform-independent, and therefore, it can be implemented on low-cost hardware for smaller systems, and the clients can run on mobile devices. The first and second examples are typical scenarios in IoT on Node-RED platform including Arduino and third-party cloud service, whereas the third example is live camera capture with object detection capability. Finally, it was also shown about how Node-RED can be used as a mobile application remotely. After the completion of the book chapter, the readers are supposed to be able to develop IoT systems using VPL-Node-RED, integrate IoT with Node-RED, to design various workflows for IoT on Node-RED, develop real-time IoT applications, and apply security features for IoT and Node-RED while using cloud-based services. Hence, IoT with Node-RED has the capability to change the entire education system, which makes better learning with good interaction and flexibility.

The variety of IoT devices in the future is expected to dramatically grow. Our Node-RED IoT platform was designed to be extendible. To model these future scenarios, we expect to support new IoT device types by using the generic framework for creating new devices. An example of such devices could be wearables that generate movement data. This type of data can be emitted at high volumes but small size. Another device type, which is expected, is an IoT device that is configurable at runtime. This would give us the ability to change the behavior of the device according to an operation plan. An example of this type of device would be a smart home thermostat. Furthermore, we also want to improve the intelligence of our smart testing framework providing machine learning libraries that can continuously learn from past data to improve prediction accuracy. Finally, empirical research can be done collecting a large amount of data in order to know the impact of virtual IoT laboratories on the students with their involvement as it helps the instructors to improve their laboratory sessions further.

Conflict of interest

The authors declare no conflict of interest.

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