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RESEARCH ARTICLE

The Interplay of Lean Six Sigma, Industry 4.0, and Dynamic Capabilities: Pathways to Sustainable Competitive Advantage in North African Context

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ABSTRACT The purpose of this paper is to study the integrated effect of Lean Six Sigma practices, dynamic capabilities, and Industry 4.0 adoption on sustainable competitive advantage. This paper studies and evaluates different effects to give support to industrialists and practitioners. The aim is to enrich the literature with a model containing several interesting concepts for achieving sustainable competitive advantage. In this study, we used a mixed study that follows a sequential explanatory model for which a survey with companies in north Africa was conducted, followed by semi-structured interviews that explain the results obtained quantitatively. This paper, for the first time on the African continent, a conceptual model dealing with the integrated effect of this concepts on the sustainable competitive advantage. The most significant result that the use of new technologies 4.0, by itself, has only limited effects on the efficiency and competitiveness of companies if it is only used from a technological perspective. Therefore, organizational changes and the introduction of management methods, based on industrial engineering, become imperative. The adoption of socio-technical and managerial approaches is also vital for any company aiming at the sustainable digitalization of its industrial processes.

INDEX TERMS Lean six sigma (LSS), Industry 4.0 (I4.0), dynamic capabilities (DC), sustainable competitive advantage (SCA), explanatory sequence model.

I. INTRODUCTION

Globalization is often associated with dynamic market environment conditions and uncertainties that further require companies to have the ability to react immediately to competitors' actions [1]. National and international markets in the 21st century have experienced complexity and a highly changing environment, characterized by confusing organizational boundaries, especially with the health crisis due to the Coronavirus.

To survive in such a market, companies need to monitor the business environment, gather intellectual information, and make appropriate and immediate decisions when they meet different market opportunities and threats to improving their performance compared to other competitors [2], [3].

The concept of sustainable competitive advantage is an essential element for companies that aim at a policy of differentiation and products with higher quality than those of competitors. It has been widely discussed by

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researchers in different types of studies. They try to tackle the paradigms that can either facilitate, generate or create a competitive advantage, such as dynamic capabilities [4], innovation [5], management tools [6] or through technology and digital transformation [7]. Existing studies generally discuss the individual or combined effect of concepts on sustainable competitive advantage. In our case, previous studies have analyzed the individual or combined effect of LSS practices, technology adoption, or dynamic capabilities on the sustainable competitive advantage of organizations. A single model that gathers and studies the combination of these three paradigms does not exist.

LSS is a powerful management approach that enables customer satisfaction, increased profits, and significant financial savings through the reduction of waste and the minimization of process variation. Furthermore, the concept of dynamic capabilities is considered an important element for the survival, growth, and competitiveness of companies [8]. Moreover, Industry 4.0 advancements have led to a paradigm shift, where strategic and operational decisions prioritize profitability and long-term sustainability [9]. Technology and digitalization finally open new frontiers and opportunities for organizations that aim to compete in national and international markets.

In the current academic landscape, a significant gap is evident: a comprehensive conceptual model that holistically examines the interconnected effects of Lean Six Sigma (LSS), Industry 4.0 adoption (AI4.0), and Dynamic Capabilities (DC) on Sustainable Competitive Advantage (SCA) is notably missing. Despite the extensive body of literature addressing these themes in isolation, there is a pressing need for a more integrated analysis of their interrelations and impacts. Particularly, the literature reveals an ambiguity in understanding the relationship between DC and firm competitiveness, indicating a need for more in-depth investigation [10], [11]. Furthermore, the dearth of empirical research exploring the nexus between continuous improvement tools and DC within the African context marks a significant void in existing research [12]. Our study aims to bridge these gaps by addressing specific research questions, shedding light on the combined impact of LSS, AI4.0, and DC on SCA, and exploring these dynamics within the unique setting of the African continent. Through this innovative approach, we aspire to provide new insights and perspectives in this field of study, thereby enriching academic understanding and offering practical implications for organizations operating in these complex environments. The study seeks to obtain answers to the following research questions (RQs), namely:

RQ1: What is the impact of DC or LSS practices or I4.0 adoption on SCA?

RQ2: What is the impact of I4.0 adoption or DC on LSS practices?

RQ3: What is the impact of I4.0 adoption on DC?

RQ4: What effect do LSS practices or DC, individually, have on the relationship between I4.0 adoption and SCA?

RQ5: What effect do LSS practices have on the relationship between DC and SCA?

RQ6: What is the combined mediating effect of LSS and DC on the relationship between I4.0 adoption and SCA?

To answer these questions, we conducted a mixed-methods study, which follows an explanatory design: A survey and interviews carried out with organizations located in North Africa. The analysis and processing of the quantitative data were realized via structural equations modeling by the partial least squares approach. Then, the qualitative study is carried out via semi-structured interviews and aims to explain the unconfirmed quantitative results. The rest of the paper is structured as follows: The next section presents the theoretical background, the hypotheses development, and the proposed conceptual model. Section II-C presents the research design and methodology adopted to conduct the study. The mixed study that follows an explanatory design is presented in section III. Section IV discusses the obtained results in the qualitative and quantitative studies. Section V covers the contributions, limitations, and future research directions. We end with an overview of the study's conclusions and research perspectives.

II. THEORETICAL BACKGROUND

A. LEAN SIX SIGMA LSS CONCEPT

LSS is the latest generation of improvement approaches [13], it is a new trend integrating the principles of Lean Manufacturing LM and the Six Sigma SS approach. Historically. These two approaches were developed separately and for different reasons. Lean was popularized in Japan by Toyota Corporation to minimize waste in their production system and SS at General Electric in America to improve product quality. The initial integration of LM and SS and its later popularity appeared in the United States, at the George Group in 1986 [14], [15], [16], [17], [17] which was the first to integrate and popularize Lean with SS [14]. Michael George of the George Group is the main reference in LSS [18]. He is one of the main LSS advocates. He states that the objective of LSS is dual. First, "to transform the CEO's overall business strategy from vision to reality through the execution of appropriate projects, and second, to create new operational capabilities that will extend the CEO's range of strategic choices in the future" [19], [20]. A LSS company can achieve overall performance by improving its dimension either financial, social, and indeed environmental [21].

B. DYNAMIC CAPABILITIES DC CONCEPT

In recent times, the concept of dynamic capabilities (DC) has evolved and matured, turning into a framework that supports sustainable growth via strategic innovation within businesses [22]. It is considered an important element for the growth, survival, and competitiveness of firms [8]. Its most important antecedents are found in the resource-based view. This theoretical approach establishes that valuable, scarce, inimitable, and non-substitutable resources are the main source of competitive advantage [23]. These DC were first developed in the paper written by Teece et al. [24] which is based on the literature addressing strategy as the baseline for DC. These are defined as: "The ability of the firm to integrate, build and reconfigure internal and external competencies to deal with rapidly changing environments" [25]. This theory is extremely precious for the development of strategic management studies, but it presents some limitations to explain how competitive advantage evolves when firms are faced with hyper-competitive environments.

C. INDUSTRY 4.0 CONCEPT

Industry 4.0 has emerged as a highly debated topic in both academic and professional circles [26]. It was first defined as the term "Industry 4.0" at the Hannover Fair in 2011 [27, p. 0]. From Industry 1.0 with the coal discovery to the fourth revolution where digitalization is its main feature. These successive revolutions and transitions are due to several factors like competition, globalization, and consumer demands. Today companies are trying to take advantage of new technologies to ensure their sustainability and keep a good reputation with their customers. Industry 4.0 contains a variety of highly developed tools and technologies that the literature has extensively reviewed. However, when a company decides to pursue this industrial revolution, it is necessary to adapt its processes and provide new skills and knowledge to all employees interested in this change, namely the proper exploitation of each technology and its proper integration.

D. SUSTAINABLE COMPETITIVE ADVANTAGE SCA

There is no common definition of SCA [28]. However, Hoffman [29] indicated that Barney [30] probably approached the closest formal definition by proposing the following: "A firm is said to have a SCA when it implements a value-creating strategy that is not simultaneously implemented by current or potential competitors and when these other firms are unable to reproduce the benefits of this strategy." The SCA must have four attributes: valuable, rare, imperfectly imitable, and non-substitutable [30], [31]. Indeed, different attributes such as, for instance, resources, technologies, information, market opportunities, and skills can, almost all, be imitated and replicated by competitors [32], [33]. However, in a rapidly changing, hyper-competitive environment, imitation by competitors, the appearance of new competitors, or the introduction of substitute products erode initial competitive advantages, preventing initially superior economic performance from being sustained in the future [34]. Managers are looking for ways to build SCA, identified as key to the success of any business, within their organizations [35].

III. HYPOTHESES DEVELOPMENT

A. INDUSTRY 4.0 ADOPTION AND SUSTAINABLE COMPETITIVE ADVANTAGE

Industry 4.0, based on innovative technologies, transforms industrial automation, overcoming manufacturing challenges and unveiling new opportunities [36]. Following the transformative role of Industry 4.0, the influence of these advancements on organizational performance has garnered the attention of scholars, particularly as organizations navigate through challenges like globalization, intense competition, and market fluctuations. Today one of the biggest challenges organizations face is finding the right way to create competitive advantage CA in the I4.0 era [37]. Several studies point to the positive effect of I4.0 on SCA. For instance, I4.0 can solicit SCA by improving the competitive position of the company, and the responsiveness to changing customer demands and individual needs [38], [39], [40]. Again, it generates new business opportunities through the remodeling of corporate strategies, supply chains, value chains, operations, and business processes, as well as stakeholder relationships [41], [42, p. 0].

Furthermore, the implementation of each new digital solution in the company aims to improve the company's competitiveness in the market and increase its profitability. The increase in the proportion of high-value-added products in global trade via increased quality with intelligent systems and manufacturing quantity, encourages more exports than imports [43]. Additional revenues resulting from the portfolio digitization, high margins achieved through larger products to be used according to customer needs, and increased market share within the core offering [41]. Besides, I4.0 enables the availability of real-time data and online processing capability with advanced algorithms, allowing an operational management approach of profit per hour at the optimal operating point available and considering all revenue with cost factors [44], [45]. This quality allows companies to respond, recognize and react quickly and intelligently to market fluctuations and increase competitiveness.

H01. Industry 4.0 adoption positively affects sustainable competitive advantage SCA.

B. INDUSTRY 4.0, LEAN SIX SIGMA, AND SUSTAINABLE COMPETITIVE ADVANTAGE

Nowadays, researchers discuss mostly the new power of LSS tools through the different Industry 4.0 techniques and technologies that have contributed to improving the results in their applications [46]. For LM, the use of new technologies that emerged with the I4.0 revolution in production systems brings a process that provides data to the Lean concept, supports and purifies defects by automating manufacturing processes, and consequently, improves production processes [47]. Singh and Singh [48] highlighted the essential role of combining Industry 4.0 technologies with lean production, showing how this integration notably enhances productivity and flexibility in the industry.I4.0 presents itself as a possible LM evolution where processes can be stabilized and refined by applying I4.0 concepts. These concepts contribute to answering the limits of LM [49], [50]. These include the flexibility of production systems to produce highly customized products by meeting deadlines and market needs. I4.0 offers a clear advantage in stabilizing Lean processes with I4.0 applications [49].

Furthermore, I4.0 still positively impacts the LSS concept especially since its projects are data-based. The fusion of the Internet of Things with the Lean Six Sigma methodology allows information availability, which was before difficult to obtain [51]. This allows organizations to better exploit big data to make operations more efficient, provide better products and services to customers [52], [53], facilitate and stimulate the role of Lean Six Sigma in seeking additional optimizations. I4.0 offers a multitude BD analysis technique that facilitate optimal and correct decision-making. Process Mining (PM) technology, for example, uses BD analysis and promises valuable support to SS and its data analysis capabilities [54]. It is also possible to make meaningful decisions using these methods at each stage of the LSS cycle considering that I4.0 is moving towards the digitization of manufacturing activities through powerful data analysis methods that enable the achievement of meaningful results from the available BD [55].

The most popular reasons for deploying LSS include: changing competitive market position or staying competitive in the international marketplace, increasing customer satisfaction, attraction, and loyalty, improving product quality, manufacturing operations, and increasing the bottom line [56], [57], [58]. Several organizations in several industries have reported significant financial savings from the use of the LSS methodology [59], [60], [61].

Lean, SS, or integrated, offer organizations several substantial benefits including increased profits, financial savings, customer satisfaction, key performance metrics, and cost reduction [56], [57]. As a result, there is a positive relationship between LSS and SCA [62]. In a study of the financial impact of LSS, Douglas et al. [63] confirm these reasons by revealing that improved sales, customer satisfaction, profitability, and cost reduction are some of the main benefits of the LSS concept.

H 2.1. I4.0 positively affects LSS.

H 2.2. LSS positively affects SCA. Therefore,

H 2.3. LSS mediates the relationship between I4.0 and SCA.

C. INDUSTRY 4.0, DYNAMIC CAPABILITIES, AND SUSTAINABLE COMPETITIVE ADVANTAGE

With the increasingly complex and rapid changes in the environment, DC have become a winning strategy for companies to acquire CA [64]. They are presented as a factor facilitating the SCA of a company [65]. The DC theory has developed from the resource-based view to explain how firms obtain a SCA [23]. It is imperative for firms to continuously create and acquire capabilities that will allow them to generate SCA over their competitors [66]. These DC are a major consideration for the CA sustainability of a company since competitive characteristics and future market conditions are difficult to predict with precision. As a result, firms need to be able to flexibly enter the market and make change decisions to respond to environmental changes or developments [67], [68]. For example, sensing capability enables companies to more actively seek and interpret information, as well as to better understand the environment they are facing [69], [70]. DC allows companies to react more quickly to competitor initiatives, better understand customer needs, be more creative in developing new products and ultimately achieve an AC [69].

The concept of Industry 4.0 has inspired both academic researchers and industry experts to investigate its potential in enhancing business performance and securing competitive edges [71]. Currently, we are observing the ascent of Industry 4.0, marked by novel technologies that are driving a technological, dynamic, and virtual revolution. This revolution is characterized by its ability to offer visualizations of the physical world, transforming how industries operate and compete. When we discuss the transformation of I4.0 from a managerial and organizational point of view, we can conclude that it is mainly about how to create DC that can change the operational, path-dependent manufacturing capabilities and resource bases that allow a company to maintain its CA [72]. I4.0 pushes companies to transform their capabilities, especially in innovation and adaptation to a dynamic market [73].

It can also be noted that new technologies are impacting rapid decision-making and coordination capabilities by helping companies improve decision-making, coordination between different supply chain activities, predictive maintenance, and inventory requirements for dynamic demand and production [74], [75], [76]. On one side, decision-making can be done in real-time through data analysis, and also in real-time, through cyber-physical systems. On the other side, the different new technologies allow information processing capabilities for complex and critical data due to the increasing volume of data available on the market and which promotes the achievement of a CA [77].

Sambamurthy et al. [78] describe that firms' use of information technology (IT) infrastructure develops these three interrelated capabilities, namely partner agility, customer agility, and operational agility, to improve financial performance [79]. It helps an organization to become more responsive to customer needs and changing business requirements. Furthermore, Mendonça and Andrade [80] studied the impact of Internet of things IoT and BD on seizing capabilities that are used to benefit from the chances and opportunities where IoT enables the connection of all objects and provides data. This data is transmitted with relevant information and then converted into knowledge that can be used by technologies like BD. Therefore, the following three hypotheses are proposed:

H 3.1. I4.0 positively affects DC.

H 3.2. DC positively affect SCA. Therefore,

H 3.3. DC mediate the relationship between I4.0 and SCA.

D. LEAN SIX SIGMA, INDUSTRY 4.0, DYNAMIC CAPABILITIES, AND SUSTAINABLE COMPETITIVE ADVANTAGE

Despite the potential benefits of operations management approaches for DC in companies, we do not find enough resources addressing their relationship. Gutierrez-Gutierrez and Antony [12] conducted a literature review with a very small sample size to study the relationship between DC and continuous improvement initiatives. In addition, Sunder and Ganesh [81] mentioned the lack of a study linking CD and LSS. The lack of such studies justifies the need for more studies to establish empirically validated conceptual linkages.

Gutierrez-Gutierrez et al. [82] studied the relationship between SS practices with team management metrics and statistical metrics on DC. they discussed the use of statistical metrics which consists of statistical process control (SPC) and other statistical tools used to improve products and processes. In addition, the team leader's competencies (black belts) were highlighted for their role in promoting the exchange of ideas and opinions, team building, and individual motivation. This impact study underlined the relationship of these two SS practices with DC of knowledge integration, organizational learning, and knowledge absorption. Additionally, Gowen and Tallon [83] pointed out that the successful creation of DC can be achieved from SS programs that rely on the development of human resource management dimensions.

This creates team systems with different belts covering statistical skills, managerial skills, project management skills, leadership skills, etc. The SS belt system allows for new knowledge in a collective system to promote a shared understanding which influences integration skills.

LSS DMAIC aims to improve existing processes through the reconfiguration of resources and the use of improvement methods. It focuses on better customer satisfaction and the achievement of new results, which directly affects the reconfiguration capabilities. In addition, Peteros and Maleyeff [84] have indicated that DMAIC aims at rationalizing the decision-making process for investors. Therefore, we conclude that this aspect improves the decision-making capabilities of companies as well as their strategic capabilities. Not only the DMAIC can enhance the DC but also the Design for Six Sigma (DFSS) which seeks to design compliant and quality products, also contributing to the improvement of innovation capabilities [85].

DC can also contribute to successful LSS implementation by reducing its critical failure factors. Coordination skills increase employee engagement, and employee involvement in an organization's activities, and increase the level of employee commitment [86].

In addition, DC that are related to knowledge management and learning, including encouraging employees to conduct experiments, which is the basis for the emergence of new revolutionary ideas [87], [88]. Also, sensing capabilities can provide the company with new knowledge related to product development, services, and process innovation [89].

There are also several synergy illustrations between LSS and DC. For example, The identification of the customer's needs is a feature within the first step of DMAIC and the seizing capabilities [90]. This type of capability also motivates companies to focus on finding solutions for their customers and to change their practices when customer feedback gives a reason to do it [91]. Accordingly, with the positive relationship we suggest, argued through literature discussed previously, between dynamic capabilities, LSS practices, and Industry 4.0 adoption, we conceptualize that the integrated effect of LSS and DC practices mediate the relationship between I4.0 adoption and SCA. Therefore, we hypothesize the following:

H 4.1. DC positively affect LSS practices

H 4.2. LSS practices mediate the relationship between DC and SCA

H 4.3. The integrated effect of LSS and DC mediates the relationship between I4.0 and SCA

Figure 1 illustrates the research model proposed in this study.

IV. RESEARCH DESIGN AND METHODOLOGY

In this study, we explore the interaction between Lean Six Sigma (LSS) practices, Dynamic Capabilities (DC), and the adoption of Industry 4.0, examining their combined influence on Sustainable Competitive Advantage (SCA). Our approach employs a mixed-methodology, integrating quantitative analysis through surveys with North African companies and complementing this with a series of semi-structured interviews. This method allows us to comprehensively examine the interplay of these paradigms and their contribution to SCA in a region where such research is notably rare. By focusing on North African businesses, our research addresses a gap in the existing literature, offering fresh perspectives on the application and efficacy of these concepts in a unique and rapidly changing business environment. The aim is to broaden the understanding of how these key elements interact and their significance in cultivating a sustainable competitive edge in an African context, thereby providing significant contributions to both management practice and theoretical discourse.

This study follows the sequential explanatory design (see Figure 2) that includes two distinct and sequential phases in which qualitative data are collected after a quantitative phase to explain the obtained quantitative data more deeply. This design has a strong quantitative orientation because quantitative data is the key element to start the process [92]. The choice of the explanatory model, which is sequential, is based on several reasons. One of them is that we will not be required through this model to validate all ten hypotheses qualitatively.

Following the gathering and analysis of quantitative data through surveys, we proceed with a sequence of semi-structured interviews to deepen our understanding. These interviews delve into the subtleties and complexities not captured by quantitative analysis, providing a fuller picture

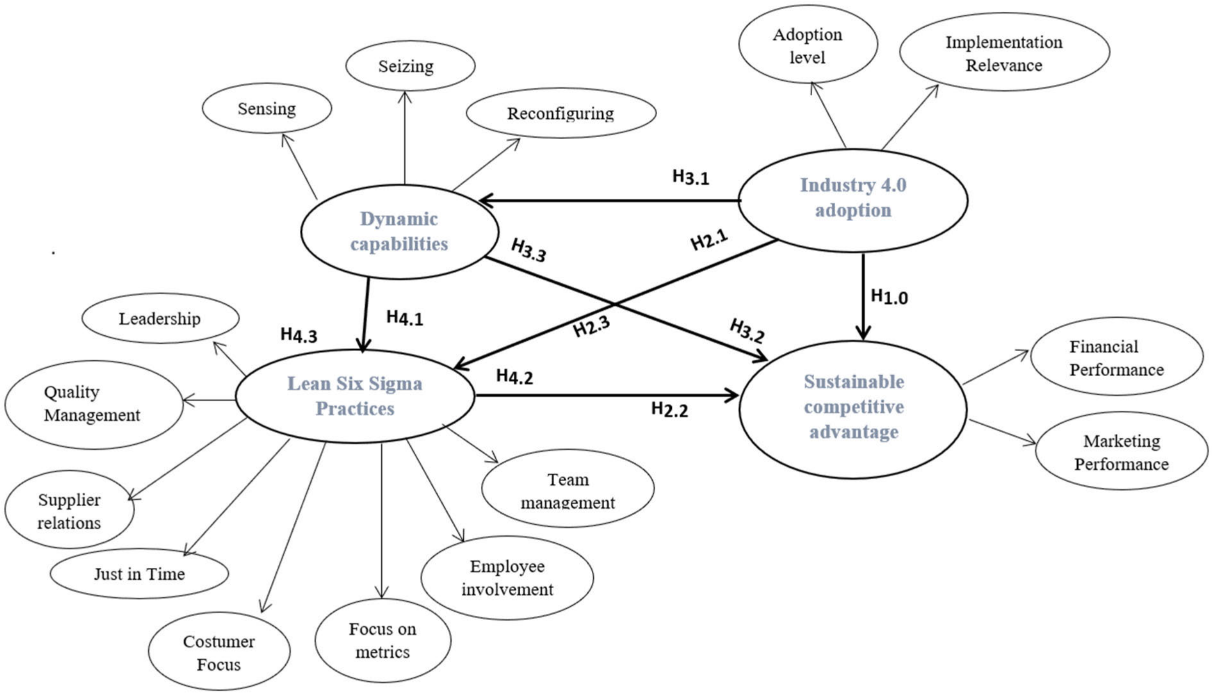


FIGURE 1. Research framework.

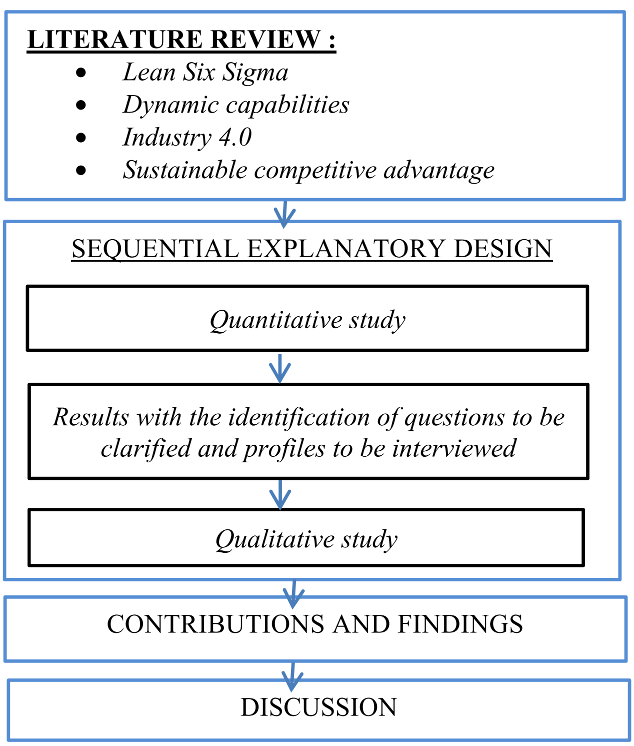


FIGURE 2. Methodology of research.

of the practices, challenges, and opportunities related to the integration of LSS, DC, and Industry 4.0.

The subsequent qualitative analysis interprets the experiences, viewpoints, and tactics of the respondents, offering detailed insights into how these components interplay to establish a sustainable competitive advantage. This sequential and explanatory process ensures our research transcends merely quantifying relationships between the variables of interest, also unveiling their intricacy and dynamism within the specific context of North African companies. Therefore, our study contributes significantly by illuminating the pathways through which LSS, DC, and Industry 4.0 synergize to support the development and maintenance of a lasting competitive edge in emerging markets.

V. MODEL EVALUATION

A. BACKGROUND OF THE DATA

The selection of the appropriate profiles is one of the main challenges in surveys as it is a key element in the reliability of the data. The profile of the participants in this study was determined before data collection was initiated. The first criteria required for participant profiles are as follows: From an engineering background and preferably in industrial, logistics engineering or equivalent; In a position of responsibility; In the same organization for at least two years; and certified Black Belt or Green Belt with extensive experience.

Before distributing the questionnaire, the content relevance and validity were assessed through a pilot study by applying the questionnaire to practitioners and academic researchers. The survey was discussed with the 10 academics and the four practitioners. Based on their feedback we were able to improve the questionnaire quality, minimize the risks of questions misunderstanding and reduce the time allocated to fill it.

TABLE 1. Participant information.

COMPANY SIZE	Large companies	62,7 %	sector	Private	87,93 %
	Medium-sized companies	29,13 %		Public	4,31 %
	Small companies	8,17 %		Semi-public	7,76 %
ACTIVITY SECTOR	Automotive	55,56 %	Professional experience	6 to 10 years	68,91 %
	Service	11,97 %		11 to 20 years	27,37 %
	Pharmaceutical	10,14 %		21 years and more	3,72 %
	Aeronautics	7,69 %	Age	30 to 40 years	72,80 %
	Construction	6,84 %		41 to 50 years	23.06 %
	Agribusiness	2,56 %		51 years and older	4,14 %
	Electronics	1,71 %	Gender	Male	76,07 %
	Other	3,53 %		Female	23,93 %

For the targeted population, we opted to collect the majority of responses from professional networks since they allow us to obtain this information easily. The selected profiles that agreed to collaborate in this research were first given the research perspective and the objective of the survey. More than 433 profiles were selected, of which 74.06% (320 responses) answered the questionnaire. According to the pre-established criteria, 83 answers were eliminated. This selection and filtration resulted in 237 responses; Table 1 provides a synthesis of the participants surveyed in the study:

B. MEASURES

The quantitative study is carried out through a structured questionnaire of 55 items regarding the four studied constructs "Dynamic capabilities", "Lean six Sigma practices", "Adoption of Industry 4.0", and "Sustainable Competitive Advantage", they were evaluated according to a 5-points liker scale. The operationalization of the variables (constructs) was carried out via a very thorough literature review of pre-existing studies. This review allowed the selection of the most appropriate instruments and scales for each item. The operationalization also included an adaptation of the vocabulary used to make the questions more perceptible and clearer for the participants. The questionnaire with all the measurement items and their descriptive statistics is presented in Appendix.

This study aims to examine the direct and indirect effect of I4.0 adoption on SCA with LSS and DC as mediating variables. In addition, the direct and indirect effect of LSS and DC on SCA and the mediating effect they may have. A model with four constructs and ten hypotheses is considered a complex model. Also, the complexity of our model via a large number of relationships and variables led us to use the structural equation modeling SEM which allows for the inclusion of unobservable variables by measuring them indirectly through indicator variables. Otherwise, our quantitative study is more adaptable to partial least squares SEM (PLS-SEM) because it accepts small samples, it can handle high model complexity and it does not require the normal distribution of the data which is not achievable on Amos and LISREL, this usually disturbs the researchers when using the collected database; Furthermore, the SEM belongs to the family of multivariate analysis where multiple variables are analyzed [93] to simultaneously examine a series of effects and relationships between these variables. This implies studying two types of models, namely: The first studies the relationship between the latent variable (a variable that cannot be measured directly) and the measurement variable (a variable that is used to present the latent variable and can be measured directly). While the second examines the hypotheses by studying the relationships between the latent variables.

C. MEASUREMENT MODEL EVALUATION

The analysis of the measurement model is the first step in the PLS analysis, and it is used to determine the relevance of the theoretically defined construct. Examination of the simultaneously ensures that the instrument is reliable [94]. This evaluation involves a conceptual, convergent, an discriminant validation, which examines factor loadings measurement model ensures that the survey questionnaire determines the variables that it is supposed to measure, an (loadings and cross-loadings of constructs with sub-constructs), average variance extracted (AVE), composite reliability (CR), and the latent variable correlations

1) RELIABILITY ANALYSIS

The construct validity of the specific items of each construct or sub-construct can be assessed by examining the respective cross-loadings and factor loadings, the purpose is to verify the representability of the variables by themselves [94]. For this aim, the external load of an indicator associated with its construct must be greater than any of its cross-loadings [95]. We have validated that all the indicators measuring a particular construct or sub-construct are greater than 0.50. The examination of the factor loadings for each

TABLE 2. Measurement model results - convergent validity.

Construct	Sub-constructs	Items	Loadings	CR Sub-constructs	AVE Sub-constructs	CR construct	AVE construct
Dynamic Capabilities	Seizing	DyCa01	0,847	0,822	0,698	0,859	0,505
		DyCa02	0,865				
	Sensing	DyCa03	0,822	0,846	0,733		
		DyCa04	0,848				
	Configuring	DyCa05	0,921	0,908	0,832		
		DyCa06	0,903				
Industry 4.0 Adoption	Adoption Level	IAL 0	0,804	0,866	0,683	0,855	0,541
		IAL 2	0,865				
		IAL 4	0,810				
	Implementation Relevance	IRI 07	0,932	0,929	0,868		
		IRI 08	0,932				
Lean Six Sigma practices	Employees Implication	LSEI01	0,854	0,891	0,733	0,905	0,516
		LSEI02	0,796				
		LSEI03	0,915				
	Focus on metrics	LSFM03	0,964	0,965	0,933		
		LSFM04	0,968				
	Leadership	LSLP02	0,936	0,927	0,864		
		LSLP03	0,922				
	Team Management	LSTM03	0,885	0,900	0,818		
		LSTM04	0,923				
Sustainable competitive Advantage	Financial Performance	PD01	0,820	0,934	0,738	0,926	0,611
		PD02	0,839				
		PD03	0,905				
		PD04	0,892				
		PD05	0,838				
	Marketing Performance	PD06	0,872	0,933	0,824		
		PD07	0,924				
		PD08	0,926				

item of the seven unobserved variables revealed that the 28 observed variables had factor loadings between 0.627 and 0.968 and all values are positive and above the recommended value [96].

2) CONVERGENT VALIDITY

For this test, the AVE must have a value of at least 0.5 for the construct to explain more than half of the variance of its indicators while the external loadings and composite reliability CR value must be at least 0.7 or higher [97]. Initially, some items were eliminated and removed to increase and improve the CR value and AVE of the constructs. This process was conducted as suggested by Hair et al. [98] who mentioned that items with loadings between 0.40 and 0.70 should be removed from the measurement if the deletion of the observed variable increases the CR in reflective assessments [96], [98]. According to Table 2, all AVE of retained measurements are above 0.5, the obtained composite reliability values exceed the recommended value of 0.70 with a range of 0.855 and 0.926, and the external loadings are strictly above 0.7. Therefore, in this study, convergent validity was achieved.

3) DISCRIMINANT VALIDITY

To test discriminant validity, we use the Fornell-Larcker criterion, which tests whether the AVE of each construct is greater than the squared correlation coefficients between the constructs [99].

In table 3, the diagonal shows the squared AVE values, and the other values show the correlations between constructs. The cross-loadings are higher than the cross-loadings among the other constructs, which justifies the representation of the latent variables by themselves. Accordingly, it can be concluded that the constructs in this study have shown significant evidence of reliability and convergent and discriminant validity. The next phase is to examine the structural model to test the proposed hypotheses

D. STRUCTURAL MODEL

The evaluation of the quality of a model is based on its ability to predict endogenous constructs. In addition, the model prediction can be established by evaluating the R2 and the Q2. The Q2 values estimated by the Blindfolding procedure represent a measure of the ability of the path model to predict the original observed values. As the difference between the predicted and original values is smaller, the Q2 increases, and thus the predictive precision of the model becomes higher [99]. However, the coefficient of determination (R2) is a measure of the model's predictive accuracy.

1) COEFFICIENT OF DETERMINATION R2

According to Hair et al. [100], an acceptable level for R2 should generally be above 0.25 for the main target constructs.

TABLE 3. Discriminant validity - latent variable correlations.

	Industry 4.0 Adoption	Sustainable competitive Advantage	Dynamic Capabilities	Lean Six Sigma Practices			
				Focus on metrics	Team Management	Leadership	Employees Implication
Industry 4.0 Adoption	0,735						
Sustainable competitive Advantage	0,354	0,782					
Dynamic Capabilities	0,462	0,430	0,711				
Focus on metrics	0,383	0,339	0,214	0,966			
Team Management	0,371	0,478	0,422	0,528	0,904		
Leadership	0,355	0,468	0,451	0,305	0,544	0,929	
Employees Implication	0,389	0,589	0,396	0,480	0,582	0,529	0,856

According to Chin [101], R2 correlation coefficient values of 0.19; 0.33, and 0.67 can be considered low, moderate, and substantial, respectively. In our case, we conclude that SCA for 0.395 can be considered moderate, DC and LSS practices can be considered weak with 0.214 and 0.307, respectively.

2) PREDICTIVE RELEVANCE Q2

According to the recommendations of Fornell and Chan, Gorondutse and Hilman [102], [103], the model will have predictive quality if the value of cross redundancy is found to be greater than 0, otherwise the predictive relevance of the model cannot be concluded [102]. When the Q2 value is greater than zero, the exogenous constructs have predictive relevance for the endogenous constructs included in the model [104], [105], [106]. According to Chin's three criteria for evaluating predictive quality [101], the obtained values of Q2 of our model are all greater than 0 and affirm that its predictive quality is moderate and adequate.

F2 Effects: Furthermore, we used the effect size F^2 to assess the change in the R^2 value when a specified exogenous construct is omitted from the model. The F^2 values in our model are interpreted according to Cohen's criteria where the effect can be considered small between 0.02 and 0.15, a medium between 0.15 and 0.35, large for a value greater than 0.35, and a value less than 0.02 reveals that the effect is absent [107]. Table 4 summarizes the F^2 which the impact of I4.0 adoption, DC, and LSS practices on SCA is 0.001, 0.036, and 0.295, respectively. This means that the impact of LSS practices on SCA is moderate, of DC is small, while that of I4.0 adoption is to be rejected ($F2 = 0.001 < 0.19$). The impact of I4.0 adoption on LSS practices and the impact of DC on LSS practices are considered low because the F2 value of these two hypotheses is between 0.02 and 0.15.

First, the structural model was checked for multicollinearity issues by examining the VIF values of all predictor variables that are less than 5. Then, the hypothetical relationships between the constructs were evaluated using the Bootstrapping procedure with 5000 resamples/iterations

TABLE 4. Effect size F2.

Hypotheses	F2	Effect
Industry 4.0 Adoption----> SCA	0,001	No effect
Industry 4.0 Adoption----> DC	0,272	moderate
Industry 4.0 Adoption----> LSS practices	0,120	weak
DC ----> SCA	0,036	weak
DC ----> LSS practices	0,118	weak
LSS practices ----> SCA	0,295	moderate

to generate confidence intervals and t-values. In addition, all bootstrapped confidence intervals were calculated based on a two-tailed test at a 1% significance level [100], [108].

The results of the SmartPLS bootstrapping process allow us to calculate the standard beta, the standard error, the t-value, and the p-value which must be less than 0.05 to accept or reject the null hypothesis Thus, when P is less than 0.05, we will say that the result obtained by the study is statistically significant [109]. Table 5 presents the test of the direct effects hypotheses where all hypothesized relationships are confirmed ($p < 0.05$) except for the effect of I4.0 adoption on SCA which is statistically rejected with a P value ≥ 0.1. Further, Figure 3 illustrates these results as well as the overall fit statistics.

VI. MEDIATION ANALYSIS

Mediation refers to examining how a third variable interacts with or impacts, the relationship between two other variables [110], [111]. Mediation is also known as a special case of "indirect effect", where it depends on strong a priori theoretical/conceptual support, which is essential to explore significant mediation effects [100], [112]. There are several approaches to analyzing mediation [113] but in our study, we relied on the method of Hair et al. [97] where total effects and specific indirect effects [113] are extracted via the

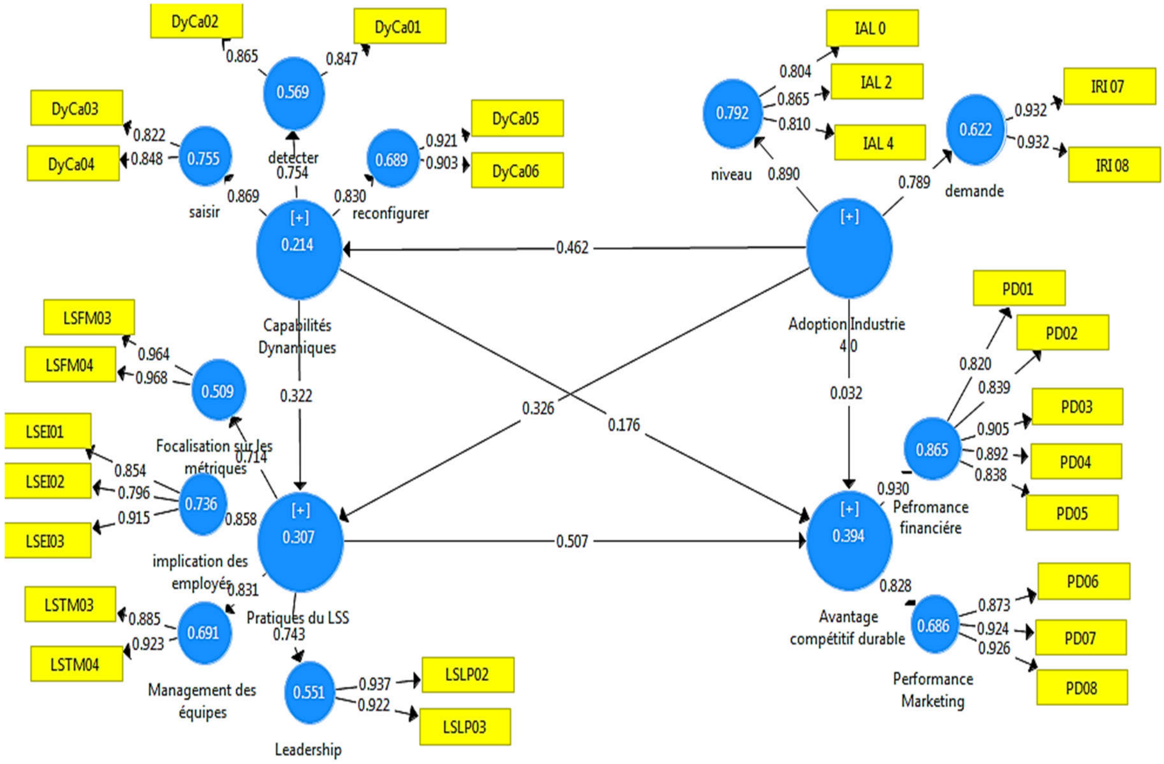


FIGURE 3. Loadings and path coefficients.

TABLE 5. Structural model results: path coefficients.

Direct effect hypotheses		Original Sample	Standard Deviation	T- value	P-Values	Decision
H1	Industry 4.0 Adoption---> SCA	0,032	0,109	0,296	0,767	Rejected
H2.1	Industry 4.0 Adoption---> LSS practices	0,326	0,103	3,173	0,002	Supported *
H2.2	LSS practices ---> SCA	0,508	0,096	5,299	0,000	Supported***
H3.1	Industry 4.0 Adoption---> DC	0,462	0,078	5,892	0,000	Supported***
H3.2	DC ---> SCA	0,175	0,088	1,994	0,047	Supported*
H4.1	DC ---> LSS practices	0,323	0,100	3,237	0,001	Supported**

SmartPLS bootstrap method. Table 6 shows an example of a mediation hypothesis study.

VII. QUALITATIVE STUDY: SEMI-STRUCTURED INTERVIEWS

This qualitative part of the study aims to discuss our main quantitative results with researchers, professors, and

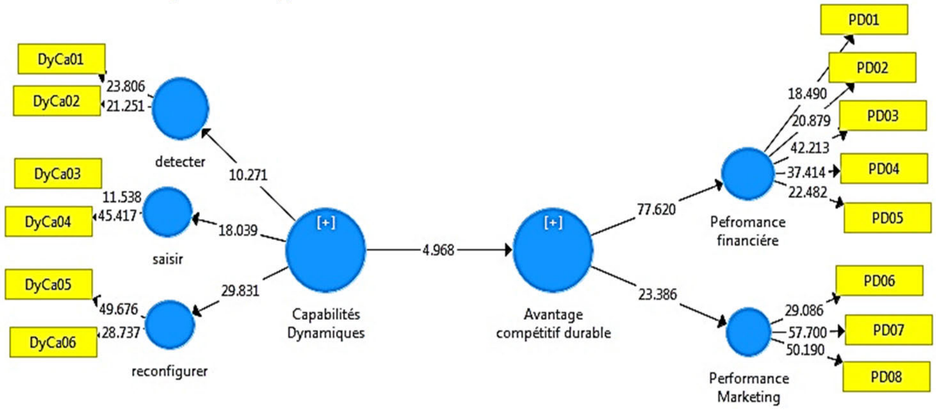
industrialists with expertise in the concepts used in our study. Our approach targets the collection of more reliable information through conducting interviews with interlocutors with relevant backgrounds. In this qualitative study, we discussed the two hypotheses H1 and H2.3 which constitute respectively the direct effect of the adoption of I4.0 on SCA and the mediation effect of LSS between these two concepts. These interviews allowed us to justify the result of hypothesis H1, which contradicts the findings of various researchers and studies in different contexts, concerning our context. In addition, these interviews justified why LSS practices support I4.0 to have SCA.

The sample interviewed consisted of 12 individuals from different disciplines and with varying expertise to enrich the discussion and results. The interviewees did not have the same scientific or academic background. They did not represent only North Africa. The interviews with participants began with a general discussion of the characteristics and results of the quantitative study. This was followed by an in-depth discussion about the results of the hypotheses selected for the qualitative study.

A. INTERVIEWING PROCESS

To conduct this qualitative survey, we developed a flow chart to synthesize the results and reinforce the obtained

TABLE 6. **Study of the mediating effect of LSS on the relationship between CD and SCA.**

	Results	Decision
1st step: Direct effect significance	Model excluding the LSS practices construct:  The path coefficient results indicate that there is a highly significant direct effect between DC and SCA with a p-value of 0.000	Confirmed
2nd step: Indirect effect significance	The significance test of the indirect effect with the mediator included is taken from the Bootstrapping analysis of the specific indirect effects, where it indicates that the indirect effect of 0.164 is significant with a P-value of 0.005	Confirmed
3rd step: significance of the mediation effect	Variance accounted For VAF VAF calculation = indirect effects / total effects VAF= 0.164 / 0.339 = 0.4838 = 48.38%. Where: indirect effect = path (DC - LSS practices) x path (LSS practices - SCA) = 0,322 x 0,508 = 0,164	Partial mediation

quantitative results (see Figure 4). This process was conducted during the period of August-November 2021 on a group of 12 interviewees from different disciplines. The result of all the interviews conducted was taken into consideration especially since the profiles were carefully selected previously and all the answers contributed to the discussion.

B. CONDUCT OF INTERVIEWS

Thirty profiles were initially invited to participate and contribute to the findings and interpretations of the qualitative study. Twelve individuals accepted our invitation with the interview mode appropriate to them. The interviews were conducted electronically via the website www.researchgate.com and Google "Gmail" messaging, by phone call, and four participants had their interviews scheduled in person at Hassan II University Casablanca. Before starting the interviews, all participants were informed about the purpose and the problematic of our study. Participants were also informed that their names would only be entered with their permission and that we would only use their information for comparison purposes. They also had the right to revoke their participation and to interrupt the interview at any time. The number and nature of the open-ended questions used in the survey were not prepared for each interviewee. However, the goal was to explore each respondent's areas of experience during these semi-structured interviews. All interviews were conducted by the same interviewer (the corresponding author) to ensure consistency between interviews and to capitalize on the results of the interviews conducted in the following interviews.

C. INTERVIEW RESULTS

The qualitative study is conducted via semi-structured interviews with 12 participants where they discussed and explained the results and the invalidated hypothesis H1 referring to the I4.0 effect on SCA. In addition, they explained the mediating effect of LSS between I4.0 and achieving SCA despite the absence of this direct effect. Table 8 reveals and synthesizes the most important reasons for the absence of the I4.0 effect discussed in the conducted interviews, as well as the role that LSS can perform to make such an effect present.

VIII. RESULTS AND DISCUSSION

Based on a thorough literature review on Lean Six Sigma, Dynamic Capabilities, and Industry 4.0, this study tested

TABLE 7. Summarizes the results of our model's hypothesis testing, including direct and mediation effect hypotheses.

Model hypotheses		P-Value	Result
H1	Industry 4.0 adoption and its technologies positively affects SCA	0,767	Rejected
H2.1	Industry 4.0 adoption positively affects Lean Six Sigma practices	0 ,002	Supported*
H2.2	LSS practices positively affect sustainable competitive advantage	0,000	Supported***
H2.3	LSS practices mediates the relationship between Industry 4.0 adoption and sustainable competitive advantage.	0,012	Partial mediation
H3.1	Industry 4.0 adoption and its technologies positively affects dynamic capabilities	0,000	Supported***
H3.2	Dynamic capabilities positively affect sustainable competitive advantage	0,047	Supported*
H3.3	Dynamic capabilities mediate the relationship between Industry 4.0 adoption and sustainable competitive advantage	0,061	Rejected (No mediation)
H4.1	Dynamic capabilities positively affect LSS practices	0,001	Supported**
H4.2	LSS practices mediates the relationship between DC and SCA	0,005	Partial mediation
H4.3	The combined effect of LSS practices and dynamic capabilities mediates the relationship between industry 4.0 adoption and sustainable competitive advantage.	0,014	Partial mediation

$P < 0.001$ = Very strong hypothesis significance or hypothesis supported ***
$0.001 \leq P < 0.01$ = High significance of hypothesis or supported hypothesis**
$0.01 \leq P < 0.05$ = Medium significance of hypothesis or hypothesis supported*
$0.05 \leq P < 0.1$ = Low significance of hypothesis or hypothesis supported
$P \geq 0.1$ = No significance of hypothesis or hypothesis rejected

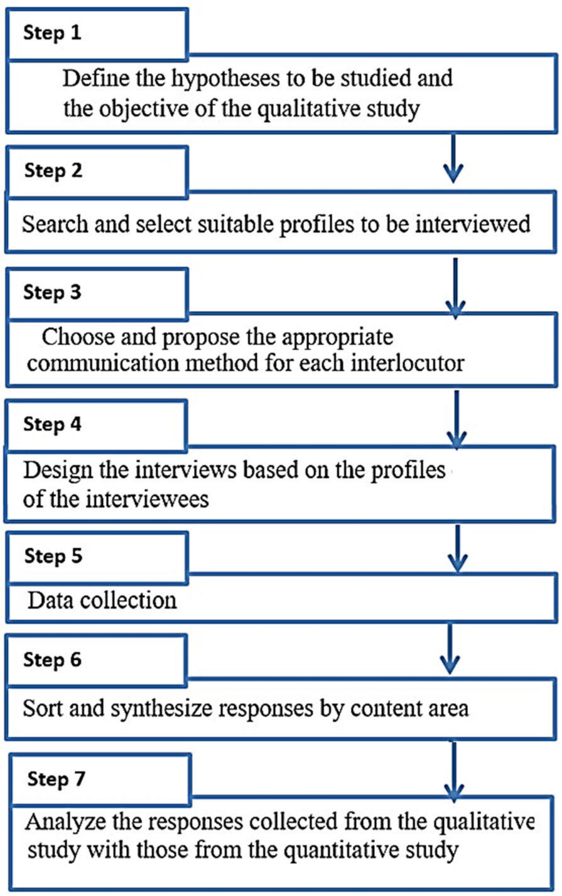


FIGURE 4. Interviewing process.

the integrated effect of these three concepts on a fourth, the sustainable competitive advantage of North African companies. Based on an elaborate model, we evaluated and processed ten hypotheses following different research methodologies. Of these ten hypotheses, the PLS analysis of our collected data revealed that two of them (H1 and H3.3) are rejected. However, the results of all the other eight hypotheses are considered consistent with the findings of the literature review.

The quantitative result of hypothesis H 1, representing the direct effect of I4.0 adoption on SCA, is not consistent with previous studies revealed by the literature. These studies, which have examined the effect of digital technologies on the achievement of SCA for companies located worldwide, confirm a significant direct effect. Temitayo et al. [114] emergence of smart capabilities. These capabilities are fundamental in boosting productivity, ensuring sustainability, securing safety, and enriching the customer experience. This effectively draws a direct connection between technological utilization and the enhancement of organizational performance metrics. In an exploratory study covering 460 companies, Lin et al. [115] implement the I4.0 strategy in China where the results showed that I4.0 has a significant impact on company performance including financial performance. Also, Büchi et al. [42] conclude that the adoption of I4.0 technologies significantly influences the company's performance via the business opportunities landed. There is an impact of new digital technologies on the different characteristics of SCA, such as the digitization of the company's portfolio that allows for additional revenues [41].

The issues discussed in these interviews include the lack of preparation of companies to digitize their processes, the deployment of technology just for the form, the lack of technological capabilities, the lack of a roadmap, the lack of human resources necessary for change, as well as the resistance to change and the lack of a culture oriented towards learning and innovation. For the participants in

TABLE 8. Synthesis of qualitative results.

Reasons for the lack of the effect of new technologies on SCA	Role of LSS as a mediating effect between I4.0 and SCA
Use of digital technology only for a technological perspective.	Preparing the platform for the digitalization by optimizing the flows.
Lack of a culture oriented towards innovation and learning (deployment of technology alone is not enough)	Creation and sustainability of a learning-oriented culture.
Adoption of technology in a non-optimized and complex environment	Reference and refers to the innovation of all production process dimensions.
Non-qualification of human resources (lack of technological skills).	Creation of a culture of change and continuous improvement.
Resistance to change.	Organization of teams (belt system).
Lack of a roadmap to digitalize processes	Team training (skills, knowledge, leadership, ...).
Lack of readiness of the processes and infrastructure to be automated.	----

these interviews, the above-mentioned causes are the main factors that prevent the impact of technology on the SCA. It is insufficient to use technology from a technological perspective; it is necessary to make organizational changes in the company, as well as to combine the use of digital technology with socio-technical approaches to exploit all its functionalities and advantages. The quantitative result of the I4.0 adoption effect on LSS is consistent with the literature results. There is evidence of a direct effect of I4.0 adoption on LSS practices. Digital technologies can directly affect data processing at each phase of the LSS project and its progress by deploying these different technologies at each step of the DMAIC cycle. Titmarsh et al. [116] highlighted that the introduction of I4.0 provides a better understanding of manufacturing process data, which increases the opportunities and expected outcomes of the Six Sigma application. Furthermore, the integration of Industry 4.0 technologies with Lean Manufacturing significantly improves its efficiency by supplementing traditional Lean principles with advanced digital tools, leading to increased productivity and enhanced waste reduction [117] this fusion of Lean Manufacturing with Industry 4.0 technologies leads to more efficient, productive, and advanced manufacturing processes [117].

Several previous works have addressed the relationship between LSS practices and SCA, including the effect of these practices on several SCA indicators. For instance, we refer to Douglas et al. [63] who confirm that the main benefits of the LSS concept are sales improvement, customer satisfaction, profitability increase, and cost reduction. The LSS implementation in a company also enables market competitiveness [118] and market share growth [119] as well as very significant financial savings [15], [56]. Sá et al. [120] conducted a case study in a metal-mechanic company, illustrating the effectiveness of Lean Six Sigma in enhancing internal communication, refining marketing processes, and customer relations. This was particularly achieved through the implementation of tools such as CRM and daily meetings (Daily Kaizen), thereby contributing to more efficient management and an improved customer service experience. These benefits and results of LSS implementation confirm the consistency of our quantitative result (survey).

The mediation effect of LSS between I4.0 adoption and SCA is considered partial. In the literature, there are some studies discussing the role of LM mediation between I4.0 adoption and firm performance. Kamble et al. [121] examined the LM mediation effect on the relationship between I4.0 technologies and sustainable organizational performance where they proved a significant mediation of LM. Popescu [122], again, how Lean principles participate in the visibility and sharing of data. He points out that with Lean and the introduction of new technologies such as radio frequency identification RFID, A transportation management system TMS, and other cloud-based applications, companies can improve their supply chains. It means much more revenue at lower costs. Narula et al. [123] demonstrated that strategically combining Industry 4.0 technologies with lean methodologies significantly enhances productivity and independence in manufacturing processes.

During the semi-structured interviews, participants also expressed the benefit and the role of management tools in achieving successful technology adoption in companies and the benefits of merging I4.0 with a management tool such as LM or LSS. These tools create and maintain a culture oriented towards learning and innovation. They prepare processes by optimizing and streamlining processes. Adding that the coordination between SS or LSS and new technologies allow a better understanding of the process and standardization of improvements, which leads to sustainable results.

Furthermore, hypothesis H 3.1 is strongly supported. This result is in perfect agreement with other studies that solicit that digitalization and the use of digital technologies positively influence the DC of companies. Big Data Analytics techniques can develop critical insight that positively impacts the companies' DC as well as the ability to gain a competitive advantage [124], [125], [126], [127]. The BDAs and I4.0 with digital technologies encourage companies to transform their capabilities, especially in innovation and adaptation to a dynamic market [73]. In Portugal, Mendonça and Andrade [80] demonstrated that the three technologies, IoT, BD, and AI, in different proportions of performance, are important in the three micro-foundations of the DC that we used in this study and specifically the capabilities of seizing opportunities.

In another study, Alghamdi and Agag [128] confirm that the use of AI-enhanced big data analytics has a significant impact on organizational capabilities, particularly in boosting innovation performance. They highlight how this technology notably increases a company's strategic agility, leading to enhanced innovation capabilities. This underscores the potential of effectively utilizing these advanced technologies to drive substantial innovation in a rapidly evolving business landscape.

The effect of DC on SCA is judged a moderate effect where this result is supported by the literature. Many researchers have certainly discussed the significant positive relationship between competitive advantage and organizational performance with DC. However, this relationship still requires further in-depth studies to understand the implication of DC and the relationship between them and competitive advantage in a more holistic way [129]. Furthermore, Teece [8] argues that DC should include sensing, seizing, and reconfiguring the ability to integrate, protect and reorganize the firm's resources to maintain the dimension of competitiveness. The study findings of Susanti and Arief [130] aimed at examining the effect of DC in generating competitive advantage, they show that DC could be implemented to establish a competitive advantage and ultimately be used to achieve better performance. However, DC cannot be used directly to achieve better performance and companies must choose the appropriate and superior capability to compete with their competitors [130].

Relying on the literature, Vu [10] states that there is not found even in the literature a clear relationship between DC and CA companies. He proved that some researchers believe that DC do not have the attributes of heterogeneity and therefore cannot be a source of competitive advantage and their impact is limited. However, he finds that there is no strong scientific evidence in the literature that supports this notion and that most of the studies were conducted in developed countries [10]. Therefore, it can be concluded that the relationship between DC and SCA remains abstract and further studies need to be conducted in this direction.

Our results for the mediating effect of DC between I4.0 adoption and SCA show an absence of mediation which contradicts the results extracted from the literature. Following the arguments of several researchers concerning the competitiveness resulting from I4.0, Azman and Ahmad [131] found that the manufacturing firm that holds dynamic technological capabilities has a greater possibility of survival. Furthermore, due to the increasing volume of data available in the market, information processing capabilities are critical. The acquisition of these capabilities is valuable for gaining CA because they are difficult to achieve and imitate [77], [132], [133].

Results examining the effect of DC on LSS are considered scarce in the literature. This finding denotes one of the peculiarities of our research that addresses it. For instance, Sunder and Ganesh [81], state that there is not a single study linking DC with LSS. Gutierrez and Antony [12] conducted a literature review showing the relationship between DC and various continuous improvement initiatives. However, the adoption of a very small sample size by these authors refers to the limited number of studies dealing with DC with management approaches. For this paper, we have used the DC literature to extract the convergences and linkages with the LSS. By focusing on the sub-elements of each construct (the sub-constructs/indicators of LSS and DC), we were able to prove that a positive effect can exist. For example, sensing capabilities allow the identification of customer needs [90] which is considered a crucial metric in all LSS projects and one of their important inputs influencing the solutions quality and the implementation outcome. Besides, reconfiguration capabilities allow aligning or redistributing competencies to meet the Supply Chain needs [89], providing the company the advantage of adaptability, which favors the success of new solutions and improvement proposals. The identification of the relationship between the two concepts DC and LSS has been confirmed quantitatively (survey) in our study where we identify the direct effect of DC on LSS practices.

The hypothesis H4.2 result is also one of the valuable results of this study given that the relationship under consideration has never been addressed before. This hypothesis presents the mediating effect of LSS practices in the relationship between DC and SCA where this mediation is found to be partial. This result remains coherent despite the unavailability of a similar study or a study dealing with the mediating effect of a management approach in the relationship between DC and the SCA. However, convergences between LSS and DC for a SCA can be found in the literature. Peteros and Maleyeff [84] find that the DMAIC roadmap aims at streamlining decision-making processes for investors, which improves decision-making and strategic capabilities, which have a positive effect on the achievement of competitive advantage. Gowen and Tallon [83] further discussed the role of the belt system in enabling new knowledge in a collective system, promoting shared understanding and eventually influencing integration capabilities. In the same context, Teece, Pisano and Shuen [24] find that a firm's ability to integrate its internal and external competencies is one of the factors that promote a rapid response in competitive environments and, as a result, obtain a SCA.

In another study, Gutierrez et al. [134] delve into the profound impact of lean practices on the evolution of dynamic capabilities in organizations. They emphasize the crucial role of lean methodologies in enhancing operational efficiency while also significantly fostering an organization's ability to adapt and transform in a competitive business landscape. This research brings to light the essential connection between lean practices and the progressive development of organizational capabilities, showcasing how these methodologies are not just tools for efficiency, but key drivers of strategic adaptability and innovation.

Further exploring this topic, Ndrecaj et al. [135] systematically review the integration of Lean Six Sigma with

Dynamic Capabilities to enhance organizational efficiency and adaptability in uncertain environments. Their study highlights the importance of combining these methodologies for sustainable performance optimization

The last hypothesis corresponding to the mediating effect of DC and LSS practices was also found to be quantitative, a mediator of the relationship between I4.0 adoption and SCA. This result can be interpreted from two perspectives: statistical and literary. According to the statistical results of the SEMs, the result on partial mediation with a Variance accounted For VAF of 21.47 is logical, especially since the mediating effect of DC between I4.0 adoption and SCA is absent in our African context. This absent effect lowered the LSS mediation VAF of Hypothesis H2.3 from 48.38 to a VAF of 21.47%. However, according to the literature, there is evidence of compatibility between LSS practices and DC [82], [83], [85]. Also, our suggestion to integrate and combine the concepts of DC, LSS, and the use of new technologies can further influence the SCA of the company. We cannot deny the role of automation that can influence the LSS results and practices. The LSS can use data processing technologies in each DMAIC phase and other digital technologies as solutions to problems encountered during its projects. It could also take greater advantage of new opportunities detected via BDA capabilities.

The same is true for DC that can be supported by new technologies from different perspectives. With digital technologies, including IoT and BDAs, environmental analysis and consideration of their external constraints can be easily achieved through these tools. LSS and DC, in a digital environment, can open up new frontiers for companies to win or have a monopoly on new markets.

The existing literature and our results are consistent in confirming the importance of deploying three concepts in achieving sustainable competitive advantage. LSS, as the latest generation of improvement approaches, DC, and I4.0 technologies adoption all play a very important role in achieving a SCA. Moreover, it is found that these approaches function better to achieve advantage when they come together in a single framework even though our quantitative (survey) result shows that the mediation is partial. We present a comparison of our results with the literature in Table 9. This synthetic table presents the findings derived from the questionnaire, incorporating novel hypotheses not previously addressed in existing literature. It aligns these findings with insights gleaned from an analysis of current literature, thereby providing a comprehensive and global overview.

The exploration in our study of the impact of Industry 4.0, Lean Six Sigma (LSS) practices and Dynamic Capabilities (DC) within North African companies reveals crucial aspects for these enterprises. The research demonstrates that integrating Industry 4.0 extends beyond the mere adoption of advanced technologies, requiring also an organizational and cultural transformation. This holistic approach is particularly relevant in environments where resistance to change and a lack of technical skills are significant challenges.

Furthermore, the study underscores the importance of LSS practices as effective mediators in the relationship between the adoption of Industry 4.0 and Sustainable Competitive Advantage (SCA). The mediating role of LSS is vital for optimizing workflows and fostering a culture of learning and innovation, thereby facilitating a more effective adoption of Industry 4.0. This finding reinforces the concept that simple technological adoption is insufficient; a comprehensive strategy that includes process improvements and skill development is necessary to fully exploit the potential of Industry 4.0.

Moreover, findings regarding the impact of Dynamic Capabilities on Sustainable Competitive Advantage indicate a moderate influence, highlighting the complexity and diversity of factors that contribute to SCA in African contexts. These insights pave the way for future research to explore in greater depth how these capabilities can be more effectively developed and utilized in the context of Industry 4.0.

The integration of Lean Six Sigma, Industry 4.0 adoption, and Dynamic Capabilities in our study aims to investigate a unique synergy to enhance the sustainable competitive edge of North African businesses. Lean Six Sigma provides a strong foundation for efficiency and waste reduction, while Industry 4.0 brings key technological innovations like automation and data analysis. Dynamic Capabilities enable adaptability to leverage these technological advancements in a changing market. This holistic integration of the three concepts addresses current market challenges and provides a robust platform for long-term competitiveness.

In the business world, the combination of these methodologies is often intuitively implemented, without fully recognizing their powerful impact. This synergy is particularly evident in the automotive industry, where companies like Tesla and Toyota demonstrate the effectiveness of this integration. Tesla merges Lean principles with Industry 4.0 innovations for enhanced efficiency and adaptability, whereas Toyota combines these principles with Dynamic Capabilities to maintain market agility. These automotive giants show that a conscious integration of these approaches, especially the inclusion of Dynamic Capabilities, can lead to significant improvements in efficiency, innovation, and responsiveness, thereby strengthening their competitive advantage in an ever-evolving sector.

For the integration of Lean Six Sigma, Industry 4.0, and dynamic capabilities in businesses can be approached in various ways, each tailored to specific organizational needs and contexts. One method involves adopting these methodologies simultaneously, where companies engage in digital transformation initiatives while incorporating Lean Six Sigma and developing dynamic capabilities. This approach allows for rapid synergy, conducive to innovation and significant improvements in a short amount of time.

Another method is sequential integration. Companies start with Lean Six Sigma to refine and streamline their processes

TABLE 9. Comparison between survey results and literature.

Hypothesis		Result	Consistent with	Inconsistent with
H 1	I4.0 adoption positively affects SCA.	Rejected	----	[115], [42], [41] and [115]
H 2.1	I4.0 adoption positively affects LSS practices.	Supported*	[49], [136], [137], [138], [139] and [140]	----
H 2.2	LSS practices positively affect SCA.	Supported***	[58], [59],[56], [62],[63], [141], [142] , [119],[143],[144],[145], [146], [147], [148], [149] and [122].	----
H 2.3	LSS practices mediate the relationship between I4.0 adoption and SCA.	Partial mediation	[121] and [122]	-----
H 3.1	I4.0 adoption positively affects DC.	Supported***	[80], [73], [124], [125], [126] and [127]	----
H 3.2	DC positively affect SCA	Supported*	[64], [150], [69] and [67]	[151], [152],[153] and [10]
H 3.3	DC mediate the relationship between I4.0 adoption and SCA.	No mediation	----	[131], [124], [125], [126] and [127].
H 4.1	DC positively affect LSS practices.	Supported**	----	----
H 4.2	LSS practices mediate the relationship between DC and SCA.	Partial mediation	----	----
H 4.3	The integrated effect of LSS and DC mediates the relationship between I4.0 adoption and SCA.	Partial mediation	----	----

before gradually introducing Industry 4.0 technologies. After firmly implementing these two stages, they focus on developing dynamic capabilities. This step-by-step approach offers a more manageable transition and minimizes the risks associated with significant changes.

Additionally, there is a hybrid strategy that combines simultaneous and sequential approaches. This flexible method allows different parts of the company to adopt the strategy that best suits their needs. For example, one department might choose simultaneous integration to rapidly spur innovation, while another might prefer a more measured progression. By adopting a tailored integration strategy, businesses can optimize their current operations while effectively preparing for future challenges, thus ensuring a competitive stance in an ever-evolving market.

In conclusion, the study contributes significantly to the understanding of the complex interactions between Industry 4.0, LSS practices, and Dynamic Capabilities. By focusing on the specific context of North African companies, not only has the existing literature been enriched, but also practical insights for leaders and decision-makers in this region have been provided. These results underscore the importance of an integrated approach, tailored to cultural and organizational specifics, to fully benefit from technological advancements in the era of Industry 4.0.

A. THEORETICAL CONTRIBUTION

The theoretical contribution is an essential element in research. This contribution can be realized in different ways, including "confirmation of existing theories, the extension of a theory to new areas, new conjunctions between previously separate theories or disciplines, generation of hypotheses, and advances in methodology. Theoretically, we were able to:

- Analyze a wide range of literature related to the effect of LSS practices, I4.0 adoption, and DC on SCA;

- Validate statistically the construct and sub-construct measures of LSS practices, I4.0 adoption, DC, and SCA which can assist researchers targeting similar research and studies;

- Study the combined effect of LSS practices, I4.0 adoption, and DC on SCA in a unique model and validate it via a mixed-methods study;

- Study the relationship between LSS practices and DC despite the lack of resources and studies linking DC with management tools in general;

- Support most of the findings and conclusions from previous studies that have addressed the relationship between LSS practices, I4.0 adoption, and DC on SCA; and

- Conduct for the first time a study on the African continent addressing the relationship between DC and a management tool.

B. MANAGERIAL IMPLICATIONS

First, the results of our study provide an overview of the effect of different paradigms on SCA, in general, and on North Africa more specifically. The reality of the adoption of new digital technologies is revealed. Conclusions on this topic were drawn through a mixed-methods study that follows a sequential explanatory model. The experience sharing has challenged us and related recommendations have been issued.

Our results provide industrialists, involved in projects related to the digitalization of processes, practical experiences, and elements that participate in the successful implementation of 4.0 while obtaining an SCA. They provide evidence that technology alone is relatively useless and that there are advantages to adopting socio-technical approaches.

Our results also confirm that the deployment of a management tool such as LSS promotes the successful digitization of processes. It allows the platform to be prepared with optimized processes and simplified workflows. It creates a culture of learning and innovation. These benefits will certainly help to choose the most suitable technology, minimize investments in technology (optimized processes) and achieve good results.

Based on our model, its constructs, and sub-constructs, we can refer to the LSS best practices that support the achievement of a SCA and participate in the successful implementation of I4.0. For a competitive company, it is also necessary to use practices that solicit DC.

C. LIMITATIONS AND FUTURE DIRECTIONS OF RESEARCH

Our study was able to initiate and discuss new theoretical and practical knowledge. However, like all work, it presents limitations. These can be exploited to open new research directions such as the following.

- The high response rate to the questionnaire was from Moroccan firms (88%) despite that the study targets North Africa for more generic results on different developing countries.

- In the semi-structured interviews, the unconfirmed hypothesis H3.3 (''DC is a mediator of the relationship between I4.0 and SCA'') was not retained. This is due to time limitations and the constraint of choosing suitable profiles for the interviews.

- The validation of the conceptual model (pilot study) was carried out by a limited number of participants. After processing the survey data, we found that it would be preferable to include questions related to the availability of technological capabilities and the reflection of the top management for the creation and development of these

capabilities. This parameter will be very useful in the analysis of the results as well as in the purification of the database and in opening new research perspectives.

- The lack of studies dealing with the relationship between DC and management tools leads to new research opportunities. Our study started with the capabilities of types: seizing, sensing, and reconfiguring. A new model with other capabilities such as innovation, integration, or learning capabilities could generate new and important results. This study acknowledges certain limitations, including the predominance of responses from Moroccan companies in our survey. While these responses provide relevant insights, future research would benefit from a more diverse sample for broader regional applicability. Time constraints and the selection criteria for interview participants also limited the exploration of specific hypotheses, notably H3.3, an area that could be further explored in subsequent studies. Although the validation of our conceptual model was conducted with a limited group, it lays a solid groundwork for future studies to confirm and expand our findings. These limitations, while presenting avenues for future research, underscore the significance and relevance of our contribution to understanding the interplay between LSS, DC, and Industry 4.0 in the North African context.

IX. CONCLUSION

Sustainable competitive advantage is the key to business success and an essential element to differentiate from competitors. This advantage allows a company to retain its customers, increase its sales, improve its overall financial performance and achieve better profit margins. This strength allows a company to face the competition both in terms of access to new markets and anticipation for the introduction of new products, faster than competitors, with a higher success rate. Therefore, it is very important to understand how companies can gain this advantage. This paper focuses on the study of the effect of three concepts on the sustainable competitive advantage of a company and which are: Lean Six Sigma, Dynamic Capabilities, and Industry 4.0. The present research improves the understanding of the different combinations between these concepts through an extensive literature review, a quantitative study conducted through a questionnaire, and a qualitative study conducted through semi-directive interviews.

For this purpose, we developed a research model based on the literature and involving the concepts: of Lean Six Sigma, dynamic capabilities, industry 4.0, and sustainable competitive advantage. The literature review explained ten hypotheses studied via a sequential explanatory model. This model includes two sequential and distinct phases in which qualitative data is collected after a quantitative phase to explain the quantitatively obtained data more extensively. The use of a targeted questionnaire and the conduct of semi-structured interviews allowed us to combine experience and statistics to achieve better results and understanding of the problem.

The quantitative study examined all hypotheses via the structural equation method using the partial least squares approach. First, the measurement model and the structural model were validated. Then, the mediation effects presented in hypotheses H2.3, H3.3, H4.2, and H4.3 were studied. The quantitative results of eight hypotheses were tested in the African context. The two invalidated hypotheses H1 and H3.3 respectively relate to "the effect of Industry 4.0 adoption and its technologies on sustainable competitive advantage" and "the mediation effect of dynamic capabilities between Industry 4.0 adoption and sustainable competitive advantage". The previous finding leads us to a qualitative study to explain results that contradict our literature review or to provide more details and explanations on a hypothesis requiring clarification.

The confirmed hypotheses relate to the positive effect of LSS and DC on sustainable competitive advantage, the effect of Industry 4.0 adoption on LSS and DC, and the effect of DC on LSS which is a first on the African continent. Also, for the confirmed mediating effect of LSS between DC and sustainable competitive advantage as a first study. The study validated the mediating effect of LSS practices in the relationship between Industry 4.0 adoption and sustainable competitive advantage (confirmed hypothesis H 2.3). The final confirmed hypothesis H 4.3, focuses on the integrated effect of LSS practices and DC mediating the relationship between Industry 4.0 adoption and sustainable competitive advantage. Since we proved through the literature a compatibility between the concepts "LSS", "DC" and "Industry 4.0", we suggested integrating these three concepts and combining them to better influence the SCA. The results of the quantitative survey conducted in African industrial companies supported our proposal.

Our results reveal a weak relationship between DC and SCA, which is unexpected considering the existing theory which strongly associates DC with financial and marketing performance improvement. This divergence could be explained by contextual variables specific to our study sample. A more detailed exploration of the operational models and strategies adopted by the companies could provide further insight into this atypical relationship.

The qualitative study was conducted through semi-structured interviews with twelve carefully selected participants. These interviews were divided into two categories, one dedicated to international profiles, and the other to Moroccan profiles including university professors, industrialists, and consultants.

The discussions addressed the invalidated hypothesis H1 (no effect of technologies on sustainable competitive advantage) and the confirmed hypothesis H2.3 (Lean Six Sigma mediates the effect between Industry 4.0 adoption and sustainable competitive advantage). The results of these interviews explain the real causes facing the absence of the direct effect of new technologies on the study population. They include:

- The use of new digital technologies just for a technological perspective without organizational change;
- The absence of a culture oriented towards innovation and learning. Having such a culture is very important in the success of digitalization and the deployment of technology alone is not enough;
- The adoption of technology in a non-optimized and complex environment;
- The lack of preparation of the processes and infrastructure to be automated;
- The lack of a roadmap to follow to digitize processes;
- Resistance to change; and
- The non-qualification of human resources (lack of technological skills).

However, in the majority of the interviews, participants addressed the role of management approaches in the successful adoption of Industry 4.0, which comes back to hypothesis H2.3. This hypothesis reveals that the presence of Lean Six Sigma with new technologies provides the company with a sustainable competitive advantage. Participants find that a management tool such as Lean Six Sigma helps to:

- Prepare the platform for digitalization through flow optimization. Lean aims at identifying and eliminating sources of waste and Six Sigma reduces the variation in processes;
- Train the teams (skills, knowledge, leadership, ...);
- Organize teams (belt system);
- Create a culture of change and continuous improvement;
- Referring to the innovation of all dimensions of a production process;
- Create and maintain a learning-oriented culture;

All the results discussed in this paper, including the qualitative results, contribute to the work of academics, practitioners, and researchers involved in the investigation of the effects of management concepts and paradigms such as dynamic capabilities, management approaches, and industry 4.0 in achieving sustainable competitive advantage. On the theoretical level, this paper contributes to study the integrated effect of Lean Six Sigma, dynamic capabilities, and Industry 4.0 technology adoption on sustainable competitive advantage. The study presented in this paper is the first of its kind in Africa and is therefore the first to be carried out with the present model, which also addresses the relationship between dynamic capabilities and a management tool. On a practical level, our paper provides several sources of information and experiences, especially on the African perimeter.

The study holds significance both theoretically and practically, enhancing current literature and providing insights for practitioners. It theoretically enriches academic dialogue by amalgamating Lean Six Sigma, Industry 4.0, and Dynamic Capabilities within a unified framework, questioning estab-

TABLE 10. Questionnaire deployed.

Construct	Sub-Construct	N° Item	Items
			1=strongly disagree, 2= disagree, 3= neutral, 4= agree, 5= strongly agree
Lean Six Sigma: (LSS)	Leadership (LP)	LSLP01	Top management encourages employee involvement in the production process.
24 items	3items	LSLP02	Visions are effectively communicated by the organization to all employees.
		LSLP03	Top management ensures personal leadership for quality improvement.
			1=strongly disagree, 2=disagree, 3=neutral, 4=agree, 5=strongly agree
	Quality Management	LSQM01	Continuous improvement is initiated by employees (Lean six sigma, quality circle, etc.)
	2items	LSQM02	Quality is integrated within the design and the methods such as error proofing (poke yoke)
			1=strong disagreement, 2=disagreement, 3=neutral, 4=agreement, 5=strong agreement
	Supplier relationship (SR)	LSSR01	Problems are regularly solved together with our suppliers.
	3items	LSSR02	Communication within the company is applied on important issues with the key suppliers
		LSSR03	Quality is considered the most important criterion in the selection of suppliers.
			1= Never, 2 = Occasionally, 3= About 50% of time, 4 = Most of time, 5= Always
	Just in Time (JIT)	LSJIT01	Processes and layout are redesigned to ensure a continuous flow of products
	2items	LSJIT02	Bottlenecks and buffers are eliminated, Kanban is implemented
			1= Never, 2 = Occasionally, 3= About 50% of time, 4 = Most of time, 5= Always
	Costumer Focus (CF)	LSCF01	Customers are actively involved in our quality process and in the design of the future product
	2items	LSCF02	The importance of the relationship with the customer is evaluated periodically.
			1= Strongly disagree, 2= Disagree, 3= Neutral, 4= Agree, 5= Strongly agree
	Focus on metrics (FM)	LSFM01	The company has a reliable data source for LSS measurements
	4items	LSFM02	Company managers systematically monitor the measures.
		LSFM03	The company's LSS measures are included in daily dashboards
		LSFM04	The company relies on reliable methods to calculate LSS metrics
			1= Very uninterested, 2= Somewhat uninterested, 3= Neutral, 4= Somewhat interested, 5= Very interested
	Team management (TM)	LSTM01	The company seeks to create a strong team spirit and a strong coordination
	4items	LSTM02	The company seeks to employ a skilled and adaptable workforce
		LSTM03	The company provides training and technological assistance to employees
		LSTM04	The company institutionalizes reward and recognition systems
	Employee involvement (EI)		**1= Very uninterested, 2= Somewhat uninterested, 3= Neutral, 4= Somewhat interested, 5= Very interested**
	3items	LSEI01	The company takes employee suggestions into consideration
		LSEI02	The company provides training for new employees in production
		LSEI03	The company gives importance to open and honest communication
		LSEI04	Employees are empowered to stop production if they detect an error
			1=strongly disagree, 2=disagree, 3=neutral, 4=agree, 5=strongly agree
Dynamic Capabilities : (DyCa) 6items	sensing 2items	DyCa01	The company actively seeks ways to advance its resources and operational capabilities.
		DyCa 02	The company frequently scans the environment to identify new business opportunities.
	Seizing 2items	DyCa 03	The company is able to act quickly to seize new opportunities.
		DyCa 04	The company is sufficiently flexible to invest in new ventures as they appear.
	Configuring 2items	DyCa 05	The company continuously recombines its resources and capabilities to align them with strategic objectives.
		DyCa 06	The company reconfigures its resources and capabilities to align with environmental and market changes
			1=never adopted, 2=2, 3=3, 4=4, 5=5
			For your company, please indicate the adoption level of the following technologies
Industry 4.0 Adoption	Adoption level IAL	IAL 01	Internet of Things
8items	5items	IAL02	Cloud computing
		IAL03	Big data
		IAL04	Advances manufacturing solutions
		IAL05	Augmented reality
			1=strongly disagree, 2=disagree, 3=neutral, 4=agree, 5=strongly agree
	Implementation Relevance IRI	IRI 06	Your suppliers see that Industry 4.0 is relevant to be implemented.
	3items	IRI 07	The company considers Industry 4.0 relevant for implementation.
		IRI 08	your customers see that Industry 4.0 is relevant to be implemented.
			1=Much worse, 2= Somewhat worse, 3= About the same, 4= Somewhat better, 5= Much better;
			Please indicate the level of improvement in the following financial performance indicators over the past three years compared to your competitors:
Sustainable competitive advantage: (SCA) 8 items	Financial Performance FP	PD01	Customer retention
	5items	PD02	Sales growth
		PD03	Profitability
		PD04	Return on investment
		PD05	Overall financial performance
			1=Much worse, 2= Somewhat worse, 3= About the same, 4= Somewhat better, 5= Much better;
			Please indicate the level of improvement in the following market performance indicators over the past three years compared to your competitors:
	Marketing Performance MP	PD06	The company has entered new markets faster than its competitors
	4items	PD07	The company introduced new products or services to the market faster than its competitors.
		PD08	The company's new product or service success rate was higher than that of its competitors.
Control variable 8 items	Company age	FA	Measured by the number of years since the companies were founded before classifying them into three intervals.
	Company classification	FS	Measured by the number of employees and then classified into three intervals.
	Business sector	IT	Business sectors were used to control differences between sectors.
	Company Sector	IL	Business Sector: Private, Public and Semi-Public
	Information about the participants	GR	Gender: Male / Female
		AG	Age: Numeric entry
		FO	participant role: Text entry
		EP	Professional experience: Less than one year / 1-5 years / 6-10 years / 11-15 years / More than 15 years

lished models by illustrating the interplay among these paradigms. This enriches understanding of competitive advantage in evolving industrial landscapes. Practically, the study's outcomes are vital for industry professionals, especially in North Africa, highlighting the need for a holistic approach that merges technological advancements with strategic management practices for sustained growth and competitiveness. This approach serves as a guide for businesses adapting to Industry 4.0, utilizing Lean Six Sigma methodologies and dynamic capabilities. The study sets a new benchmark in the field, promoting further research into the synergies between technology, operational excellence, and dynamic capabilities. It paves the way for comparative studies across different geographical contexts and industrial sectors, thus broadening the model's scope and applicability. In conclusion, the study offers an innovative perspective on achieving sustainable competitive advantage, bridging theoretical concepts with practical applications, and directing future research in the domain.

To summarize, our model studies the integrated effect of Lean Six Sigma, Dynamic Capabilities, and Industry 4.0 concepts on sustainable competitive advantage. But the quantitative results led us to study the reasons leading to the failure of African companies aiming at competitiveness through new technologies. In the success of digitalization adoption initiatives, the important role of socio-technical and management tools such as Lean Six Sigma and Lean Manufacturing is widely demonstrated.

APPENDIX

See Table. 10

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