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DIGITAL SHADOW AND DIGITAL TWIN INFRASTRUCTURE USED AS CATALYST FOR PRODUCTION VIRTUALIZATION AND RESILIENCIES IN THE TEXTILE INDUSTRY

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ABSTRACT

Traditional and technological ineffectiveness results in poor product quality, inadequate performances, and problems with inclusive development. Developing nations, including Africa, like Ethiopia, are weak, traditional, fragmented, and poor in technological capability, with weak and deprived improvement strategies. The goal of this study is to look into what happens when digital shadow and digital twin infrastructure is used to speed up production virtualization and make the textile industry more resilient. The impacts of digital twin and digital shadow infrastructure on supply chain visibility and production performances using both qualitative and quantitative analysis were employed. SPSS, AHP, and the mind map analysis were also employed in this study. The result indicates that an integrated and innovative digital twin infrastructure has great impacts on the production visualization, process innovation, supply chain optimization, and industrial resilience in the textile industries. Particularly, the digital twin strategies have the highest positive impacts on raw material visibility, process design flexibility, product optimization, and supply chain agility in the textile industry. Both digital shadow and digital twins have positive impacts on agility and industrial resilience (37.88%), real-time monitoring and analysis (27.73%), supply chain optimization (17.43%), and production visualization (16.96%) from the highest to the lowest, respectively. Likewise, the two strategies provide improved performances on production sustainability and agility and are vital for inclusive development in the manufacturing industry in general and the textile industry in particular. Also, digital twin infrastructure is used as a catalyst for supply chain agility and distribution performances of the textile industries. Further investigations shows that digital strategies have the potential ability to connect and collaborate with individuals (76%), engineering design (71%), production capability (65%), and raw material utilization in a virtual and visible manner (63%), respectively, from the highest to the lowest. This study provides significant insights for researchers, experts, and professionals, helping them gain a more inclusive understanding of digital twins. The findings also demonstrate the significant impact that DT implementations and stimulating sustainable and virtual textile production practices have.

Keywords: Digital Twin, Digital Shadow, Textile Industry, Production Virtualization, Textile Innovation

1. INTRODUCTION

1.1 Rational, design and research question

Digitalization and technological revolution is a forward look at a range of developments that have the potential to support sustainable and improved productivity and performance on manufacturing industries (Kroll, Horvat, & Jäger, 2018). According to (Ezell, 2016) investigated that whether "industry 4.0," as in Europe, the "industrial internet of things (IoT)," as in the United States, or just "smart manufacturing," the application of information and communication technology (ICT) to every facet of manufacturing is in the midst of reshaping modern manufacturing. Traditional and technological in-efficiency results on poor product quality, insufficient technological capability, problems on inclusive development, poor production capacity, weak work environment diversity (Damtew,et.al, 2021) (UnitedNations, 2020) (UNCTAD Secretariat, 2021). Ordinarily, digital enabling and cloud computing strategies have used on supply chain integration process provides to a link of customers, manufacturers, and suppliers who, using management techniques, work together to optimize their collective performance within the creation, distribution and support of an outcomes (Attaran, 2017) (Lassar, Haar, Montalvo, & Hulser, 2009, Fabbe-Costes & Jahre, 2007).

But in developing nation including Africa like Ethiopia, there's weak traditional, fragmental, non-integrated, weak, and underdeveloped supply chain process and poor improvement strategies (Dametew et.al. 2016, Georgise et.al, 2014, Abegaz, 2013). These result in inefficient performance, problems in inclusive development, and poor in business virtualization at the national, regional, and global levels.

Further, digital connectivity and the new manufacturing process enablers have great impact on the overall performance of manufacturing systems (Bastas A. , 2021) and productivity manufacturing industry (Damtew, 2023) (Ratlif, 2016). The big data analytics, the internet of things, mobile computing and cloud computing are technological trends that influence on production processes, products, services and business strategies significantly (NilsUrbach & Jeanne, 2017). Digital revolution is a tool for renewal, simplification and improvement that must be incorporated into our approach to principle, strategies and development policy. Therefor the adaptation and implementation of digital technologies including internet of things (IoT), cloud computing, big data analytics (BDA), Automation and Robotics are the main technologies and solutions which have accelerated digital transformation in a business environments (Pieriegud, 2018). As shown in the figure1 the digital revolutions have highly revolved in the business process for improve performance and use information technology to become more productive, improve quality, and reduce business cost (Damtew, 2023), (Aviles, 2015). This digital transformation provides a bridge between software applications and automated information processing and is becoming the connection that binds the manufacturing processes that design, produce, enable and maintain all modern industry process (Sharmin Attaran, 2024) (Alie Wube & Frank, 2017).

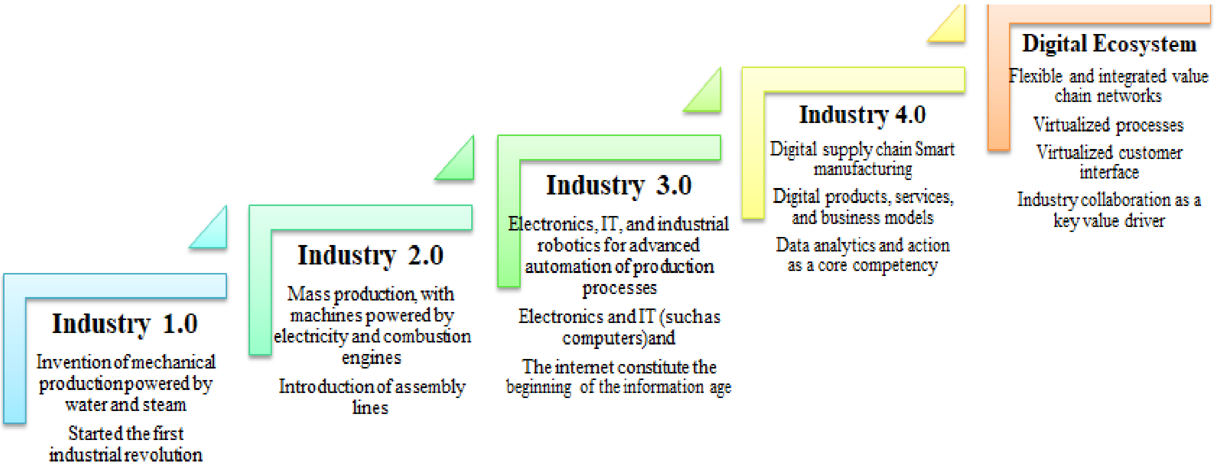

Figure 1. Digital evolution and industrial revolution in business process, (The Author adopted from (Schrauf, 2016)

Massive studies (Tinankoria Diaby, 2017), (Miller, 2016), (Rajleen Kaur, 2014) have been discovered the roles of digitalization and technological revolution impact on firm performance and competitiveness of manufacturing industries. Despite these advancements, the manufacturing and production industry grappled with numerous challenges, notably the pressing need for enhanced environmental sustainability and heightened operational efficiency and productivity (Damtew, 2023), (Alie Wube & Frank, 2017). Also digitalization and innovation textile practice of developing countries including Ethiopia there are infant and non-integrated, poor technological capability and digitalization practices(Damtew, Borena, & Yilma, 2021),(Dametew & Ebinger, 2017).

1.2 Digital Twin

A Digital Twin is a virtual model of a product, service, or process, representing one of the technologies that have a high potential for use. Besides (Lampropoulos, 2024)investigations digital twins play an important role in critical infrastructure as they can improve the security, resilience, reliability, maintenance, continuity, and functioning of critical infrastructure in all sectors. Due to multiple domains and multiple advantages, DT is now being used to represent more complex entities such as assembly line processes, warehouses, and transportation networks (Sharmin Attaran M. A., 2024). This provides to enable product and services by detecting them sooner, designing and construction better products, and predicting outcomes more efficient and effectively.

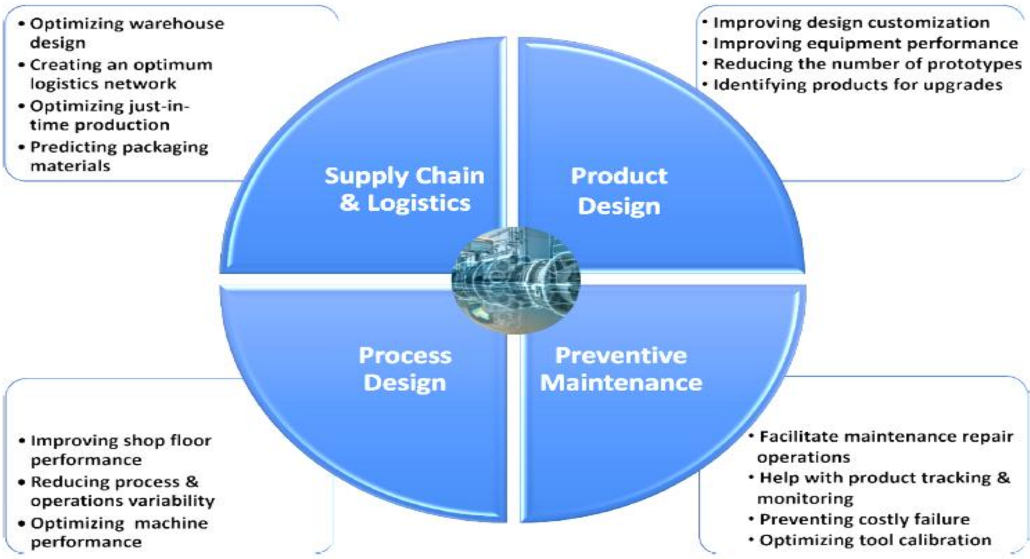

Figure.2. Role and Applications of DTs in Manufacturing (Sharmin Attaran M. A., 2024)

In the current production process engineers provides to use the virtual model generated by digital enabling tools like DT during the design phase to test different designs before manufacturing real objects. Also (Damtew, 2023) shows that digital twin (DT) strategies have been a useful tool to visualize, realize, analyse, and utilize materials in the manufacturing industries. This strategies not only digitalization production process but also provides to integrate raw material accessibility, product quality, and delivery service systems into the production line or entire supply chain process. Further the adoption and development of digital twin strategies have hampered by a number of factors in the manufacturing and textile processing industry (Damtew, 2023) (Dimitrios Piromalis and Antreas Kantaros, 2022). Also (Sharmin Attaran M. A., 2024) shows that despite the undeniable potential of DTs, they still cannot differentiate themselves from simulation technologies, and their application and adoption remain limited. This needs further investigations for the application and roles of digital twins and digital shadows in industrial applications. In addition to this (Damtew, Borena, & Yilma, 2021), (Miller, 2016), (Prepletaný, 2013) (Forum, 2013-14) shows that low income countries including Ethiopia, and other developing companies and business process are considered as low performance and lower competitiveness in innovation, digitalization and virtualization practices. This needs digital, integrated, flexible, and smart digital infrastructure for the performances on production virtualization and industrial resilience. Also (Sharmin Attaran M. A., 2024) study shows that airlines operate with bulky and inflexible systems shaped by the stringent rules and regulations that govern the industry. This impact on the performance, competitiveness, and contributions of the sectors in the global economy. But the digital twin infrastructure creates a virtual model that emulates the real-time functioning of a spacecraft. This needs further study and development of digital twin infrastructure to improve manufacturing performance and resilience to a higher extent. This study is designed to study digital shadow and digital twin infrastructure used as a catalyst for production virtualization and industrial resilience. The primary objective of this study is to investigate the concept, trend, and practices of digitalization; the roles of digital twins and digital shadow in the industrial revolution; and the impacts of digital twins on virtual performance and industrial resiliencies in the textile industries were studied.

2. LITERATURE REVIEW

2.1. The Impacts of Digital Twins in the textile Manufacturing Industry

Digital twins can be created for assets, production lines, machinery, control systems, and other real-world situations in manufacturing facilities. The operational and simulation stages of a product or process lifecycle are handled by digital twins. Engineers can learn more and see the production from a wider and deeper perspective thanks to the digital representation of the production process. Digital twins play a crucial role in advancing process manufacturing across various stages. You are now acquainted with the four categories of digital twins utilized in process manufacturing: component twins, asset twins, system twins, and process twins (Damtew, 2023), (Wedel, 2023). Each type contributes to enhancing productivity and efficiency within your facility. In the digital twin framework, component twins provide engineers with a deeper insight into the specific characteristics of individual parts, enabling them to assess and test these components for durability, stability, and efficiency. This process includes verifying proper functionality, conducting stress tests, and performing other evaluations. By simulating real-world conditions for each part, component twins enhance performance and extend the operational lifespan of the relevant components, while also facilitating more accurate predictions regarding potential repair or replacement needs. In the subsequent stage, asset twins can be composed of multiple component twins or can utilize data derived from them. Asset twins allow for the aggregation of components into a comprehensive asset or product, enabling the tracking and analysis of the entire asset. System or unit twins are employed to illustrate the interactions among assets. Plant managers leverage these twins to optimize the collaboration between assets, thereby enhancing performance and minimizing wear and tear. Unit twins provide users with the opportunity to experiment with systems, seeking methods to achieve maximum efficiency and offering insights for new business opportunities that optimize all related processes (Awwal Sanusi Abubakar 1, 2022).

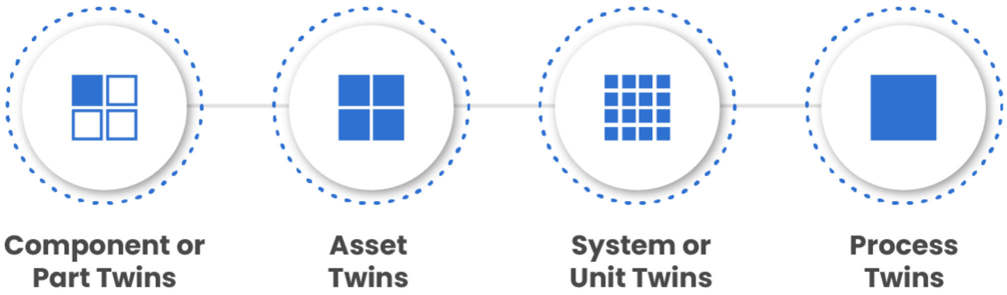

Figure.3. Types of Digital Twin in Manufacturing Industry

Process twins integrate system twins into more extensive and intricate sets of processes or workflows, often covering the entire facility. Plant managers utilize process twins to comprehend and analyse the collaboration among various units within the plant or process. These tools are employed to monitor performance, timing, and coordination across all units, ensuring system synchronization. By utilizing a process twin, one can simulate the effects of adjusting inputs, such as the rate of raw material feeding, temperature, and unit vibrations, to observe their impact on outputs, all without the risk of wasting resources on unsuccessful experiments or disrupting workflows. Additionally, a process twin enables users to track essential business metrics, thereby enhancing their decision-making and strategic planning.

2.2. The roles of digital shadow in the manufacturing industry

Based on the level of data integration, there are three subcategories of digital twins: digital model (provides two-way manual data flow between physical and digital objects), digital shadow (provides automatic data flow from a physical object to a digital object, feedback is manual), and digital twin (provides two-way).

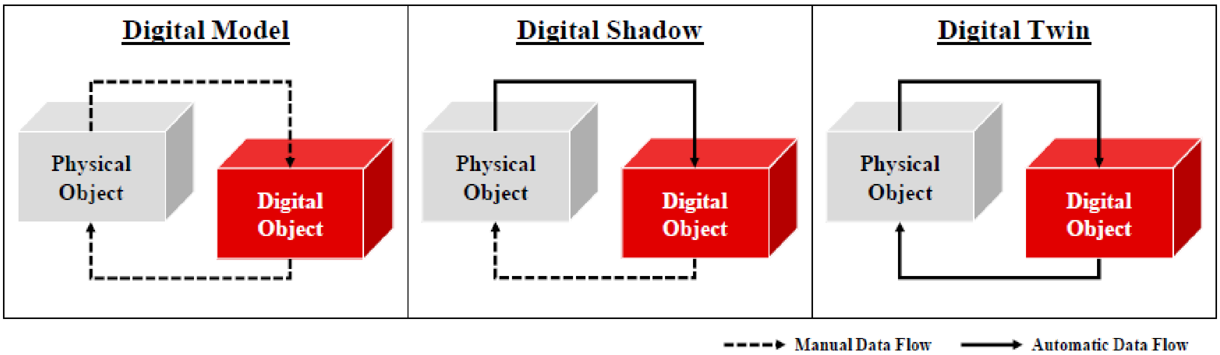

Figure.4. The relation between the concepts of DM, DS(and DT((Nicholas Frick 1, 2024)

In the manufacturing industry, a "digital shadow" refers to a constantly updated, real-time digital representation of a physical production process, capturing data from sensors and machines across the factory floor, allowing manufacturers to monitor and analyse production activities, identify potential issues, and optimize operations through data-driven decision making, essentially acting as a critical tool for improving efficiency, quality control, and overall production agility. Production innovation and process optimizations in textile production is significantly augmented by digital shadows. As show the figure below the digital shadow is where there is a physical item and its digital counterpart. The flow of data is automatic from physical part to digital part and manual from digital part to physical part. There is both, manual as well as automatic flow of data in a digital shadow. On the other hand digital twin is where there is a physical item and its digital counterpart and the flow of data is automatic from physical to digital and vice-a-versa. There is no manual flow of data in a digital twin as IoT collects data from the sensors and provides it to the digital counterpart of the physical object.

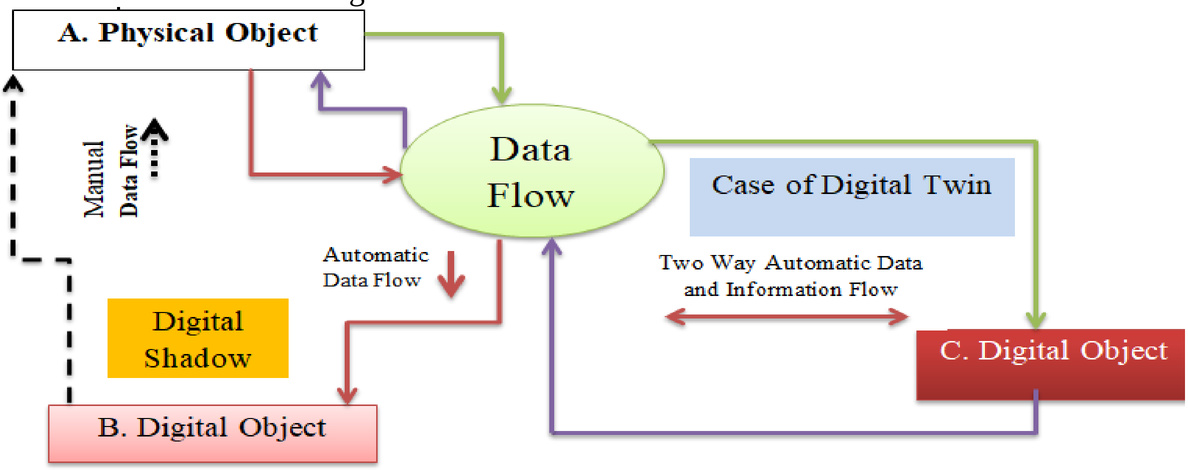

Figure.5. Data Flow Types on Digital Twin and Digital Shadow

Table.1. The Role and limitations of Digital Twin and g Digital Shadow In the Manufacturing Industry

References	Trends and key Contributions	Gaps and Limitations
(I. Jayalakshmi, 2024)	Digital twin real-time visibility quality control, and agile innovation in in the supply chain process	-Not considers the entire manufacturing process -The study not empirically investigated -Limitations of analysis tool and critical investigations
(Christian Brecher a, 2021)	-Digital Shadow provides to improve decision making -Reduce time and cost in manufacturing	-Analysis, tool, Not we studied -Provides not comparatively see with other digital strategies
(ünther Schuh, 2020)	-Investigated the roles of digital shadow based on data lake -Production planning and control	*Only considers the roles of digital shadow roles on production planning and control *the impacts of digital shadow on production performance , supply chain condition and related issues were not considered.
(Sapel P, 2023)	*Investigated the limitations of the previous research on seamless integration of Digital Shadows in production process *Asset Administration Shell introduced to enable the digital shadows benefits	The models developed based on theoretical study and not supported empirical investigations
(Nicholas Frick 1, 2024)	*Identifies concepts of digital shadows relevance in industrial environments -Value stream design model is defined	The study only depended on literature analysis of the specific design element
(Yuxin Zhang W. D., 2022)	-Investigates and analyses the theoretical connotation and research progress of digital thread and gives a complete definition of digital thread from the perspective of the combination of digital thread and digital twins.	-Limited only theoretical investigations -Not See other digital strategies
(Mohd Javaid a, 2022)	-Application of industry 4.0 improved the flexibility of the entire manufacturing system	-only industry 4.0 impossible to improve the entire manufacturing systems -this strategy limited only production process but not lifecycle of the manufacturing process

3. METHODOLOGY AND DATA COLLECTIONS

Both qualitative and quantitative approaches were employed for this study. Drawing upon powerfully selected case studies to evaluate how companies can develop and use digital enabling tools and strategies to improve performance and inclusively develop manufacturing industries. We have deeply considered the progress, limitations, and success of the selected companies in inclusion, equity, diversity, resilience, innovation, and performance conditions for sustainable development. These considerations mainly provide an input for optimizing digital and proactive model development for improving performances in visibility, visualization, virtualization, innovation, production optimization, digital sustainability, and inclusive development of manufacturing industries in general and textile sectors in particular. For the analysis process, qualitative data were supported with the quantitative analysis. The expected result can be triangulated while the researcher utilizes qualitative and quantitative data types in the data analysis. The collected data analysis was mainly performed using SPSS, AHP, and Mind Map analysis tools.

4. RESULT AND DISCUSSION

4.1. Correlation Analysis and Result

This section shows the impacts and roles of digital twin and digital shadow impacts on manufacturing industry performances. Particularly, the study clearly shows the roles of the two technological advancements used as catalysts for production virtualization and resilience in the textile industry. Mainly, the application of digital shadow and digital twins has a great positive impact on the textile industry in terms of process innovation and optimization, real-time monitoring and analysis, process agility and industrial resilience, and supply chain optimization. Using the various performance indicators, including the impacts of digital shadow and digital twin in the textile resilience and production virtualization, was investigated. According to the bivariate correlation analysis shown in the table below, the positive impacts of digital shadow and digital twin on process innovation and optimization, real-time monitoring and analysis, process agility and industrial resilience, and supply chain optimization in the textile industry were found. The adoption and application of digital shadow and digital twin strategies have the highest positive impacts on collaboration with individuals, flexible engineering design, and higher production capability and utilize the raw material from the suppliers in a virtual and visible manner. This implies that, in the current digital business, digital twins and digital shadows have a great positive impact on manufacturing industries. Not only this, but also without a strong digital infrastructure, firms cannot compete in the current digital and sustainable economic environments.

Table 2. The impacts of digital shadow and digital twin on resilience's and production virtualization

Correlations							
		DT	DSh	PV	AG	SCO	RDA
Digital Twin	P.Correlation	1					
Roles of Digital Shadow	P.Correlation	.368	1				
Production Visualization	P.Correlation	.515**	.486**	1			
Agility And Industrial Resilience	P.Correlation	.566**	.478**	.377	1		
Supply Chain Optimization	P.Correlation	.404*	.276	.254	.038	1	
Real-Time Monitoring And Analysis	P.Correlation	.360	.605**	.501**	.308	.041	1
**. Correlation is significant at the 0.01 level (2-tailed).							
*. Correlation is significant at the 0.05 level (2-tailed).							

Further investigations show that the digital shadow and digital twin have a great positive impact on manufacturing industry performances in terms of production visualization, agility, industrial resilience, supply chain optimization, and real-time monitoring. Nevertheless, the impacts on the various performance indicators are different from scenario to scenario. For instance, the table above shows that digital shadow and digital twin technology have the highest positive impact on enhancing textile industry performances. Consequently, promoting the adoption and implementation of digital shadow and digital twin technology has the highest and most positive impact on the overall performance of production performance and manufacturing resiliencies shown in the figure below.

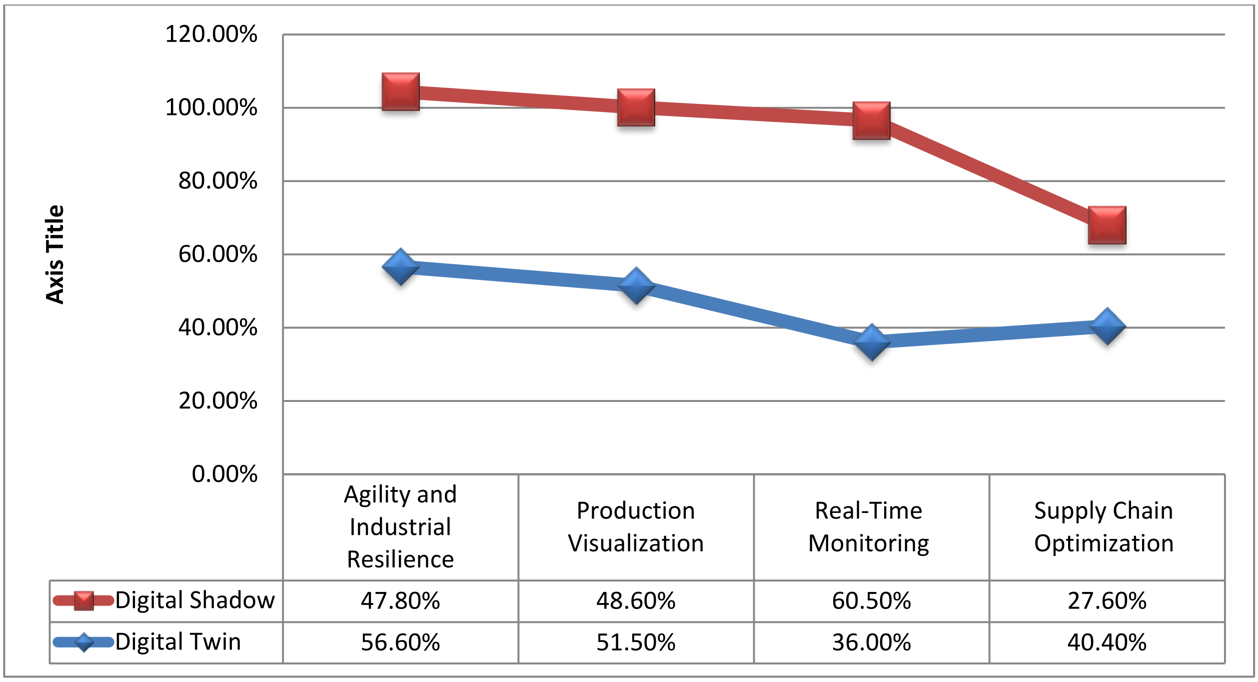

Figure.6. Correlation Results on Digital Shadow and Digital Twin influences Industry Performances

4.2. AHP-Analysis and Discussion

As a methodological approach, the Analytic hierarchy process (AHP) is used for the empirical investigations of this study. Commonly this AHP tool provides to evaluate the relative values of all criteria, comparing alternatives for each particular criterion and defining the average importance of alternatives. Furthermore, the AHP tools are one of the commonly used tools for the decision-making process on the enables decision-makers to determine the effects of many complicated and uncertain situations. Thus, this AHP analysis process supports decision-makers with setting priorities allowing for their purposes, knowledge, and experience. Therefore in this study, the AHP evaluation process involves the following six essential steps(Lee et al., 2008), (Lee et al., 2008).

i. Define the unstructured problem

ii. Developing the AHP hierarchy

iii. Pair-wise comparison: For each element of the hierarchy structure all the associated elements in low hierarchy are compared in pair-wise comparison matrices as follows:

$$A = \begin{bmatrix} 1 & \frac{w_1}{w_2} & \cdots \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & 1 & \cdots \frac{w_2}{w_n} \\ . & & \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \ldots 1 \end{bmatrix} \text{------ (1)}$$

Where A = comparison pair-wise matrix, w = weight of element or alternatives.

iv. In the fourth step the relative weights of the criteria can be determine: In this stage the relative weights (W) of matrix A is obtained from following equation: $A * W = \lambda max * W$, λ_{max} = the biggest eigenvalue of matrix A, I = unit matrix the vectors.

v. Check the consistency: The consistency index CI and the consistency ratio CR for this matrix that should be calculated by the following formulas$CI = \frac{\lambda max - k}{k-1}$. The formulation of CR is:$CR = \frac{CI}{RI}$ Since the consistency index of a randomly generated reciprocal matrix shall be called to the random index (RI), with reciprocals forced.

vi. In this stage the decision maker makes to the overall rating of the criteria: The relative weights of decision elements are combined to obtain an overall rating for the alternatives as follows:

$$w_i^s = \sum_{j=1}^{m} w_{ij}^s w_j \qquad ,i = 1,\ldots,n \quad , \ldots\ldots.. (2)$$

Where, $w^s i$ = total weight of site i

4.2.1. Application of AHP Analysis

While the above procedures are applied in the following sections. Therefore, the AHP analysis initially breaks down a complex multi-criteria decision-making problem into a hierarchy of interrelated decision elements including the criteria and decision alternatives. Followed by the objectives, decision criteria and alternatives are arranged in a hierarchical structure similar to a family tree. Once the problem has been decomposed and the hierarchy is constructed, the prioritization procedure starts in order to determine the relative importance of the criteria manufacturing industry performances. The following section the performance indicators of digital shadow and digital twin technology influence in manufacturing industry were considered. The production visualization, agility and industrial resilience, supply chain optimization and real-time monitoring are considered as the sub-criteria on the evolution and the investigations process. While virtualization, resiliencies and inclusive developments considered as the impacts of the digital technology application to manufacturing industries.

4.2.2. Analytical Hierarchal Process Results

Using AHP—Analysis, the impacts of digital shadow and digital twin on production virtualization and process resilience in the textile industry were put in the following sections. With the critical consistency ratio of 0.1, the impacts of digital twin and digital shadow have been shown in the table below.

Table.3. FAHP Alternative-Main Criterion-Matrix Result

Driving Technologies	**Alternative Performance Indictors**			
	Agility and Industrial Resilience	Production Visualization	Real-Time Monitoring and Analysis	Supply Chain Optimization
Digital Twin	80.00%	75.00%	33.33%	50.00%
Digital Shadow	20.00%	25.00%	66.67%	50.00%

According to these multi-criteria decision-making results, in the textile industry, the agility and industrial resilience, production visualization, real-time monitoring, and supply chain optimization are highly improved with the application of digital twin strategies from the highest to the lowest, respectively. Nowadays, digitalized strategies, including digital shadow and digital twin, are widely accepted as a best practice for manufacturing businesses on a global level. Due to the digital twin's and digital shadow's effectiveness and acceptability in increasing performance and increasing effectiveness, its use has spread to non-production organizations. A digital twin-enabled production process may estimate data received from numerous sensors, cameras, and other devices to anticipate the overall performance and production conditions of manufacturing industries. Based on this empirical analysis, we found that the adoption and application of digital shadow and digital twins have the benefits of flexibility, resilience, production virtualization, and optimizing supply chain processes in the textile and apparel industries.

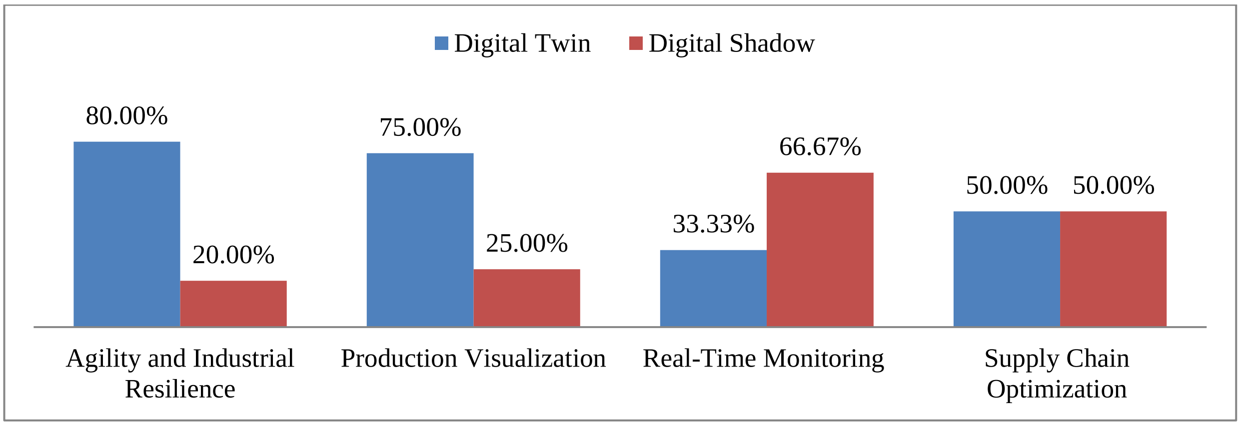

Figure.7. The Roles of Digital Shadow and Digital Twin on Industry Performances

Our investigation also found that the digital shadows have the highest positive impacts on real-time monitoring, supply chain optimization, production visualization, agility, and industrial resilience from the highest to the lowest, respectively. This implies that a digital shadow mainly refers to the flow of data automatically from the physical part to the digital part and manually from the digital part to the physical part. Due to these reasons, the digital shadow is not more effective for production virtualization and process agility compared to supply chain optimization and data monitoring. While digital twins are highly important for system virtualization and agility. Because the digital twin provides a transformation and flow of data from the physical item and its digital counterpart, the flow of data is automatic from physical to digital and vice versa. All the systems are integrated and digitalized; there was no manual flow of information, and the data in the case of digital twin strategies.

Table.4. The commend results and main criteria weighting

The Key Performances Indicators	Percentage Values
Agility And Industrial Resilience	37.88%
Real-Time Monitoring and Analysis	27.73%
Supply Chain Optimization	17.43%
Production Visualization	16.96%

Furthermore, our AHP result indicates that the digital shadow and digital twin have a great impact on process optimization and innovation processes in terms of raw material visibility, process design flexibility, and product optimization. Also, production visualization, real-time monitoring, agility, and industrial resilience are highly enabled with the adoption and application of digital shadow and digital twin strategies in the manufacturing industries.

This implies that firms highly invest in digitalization and technological revolutions for the performances and comparative advantages in the global markets. Moreover, the supply chain optimization, the digital twin, and the digital shadow strategies provide a catalyst for supply chain agility and distribution performances in the textile industries. In the supply chain process, the two strategies have a high influence on connecting and collaborating with individuals (76%), engineering design (71%), production capability (65%), and raw material suppliers in a virtual and visible manner (63%), respectively, from the highest to the lowest.

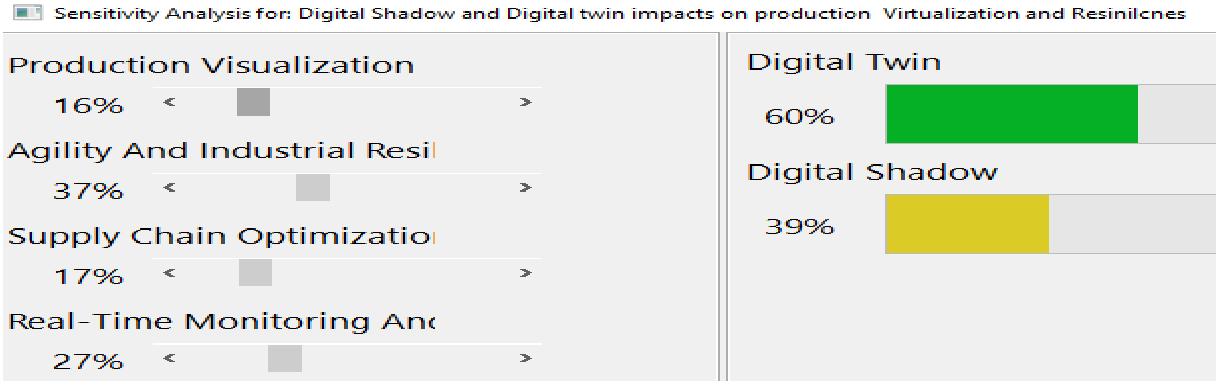

Figure.8. Sensitivity analysis result on the impacts of digital shadow and digital twin on performances

Also, the sensitive analysis result in the following figure shows the digital twin has the highest impacts on textile resilience and production virtualizations. While the digital shadow strategies also have the second and positive impacts on the overall performances.

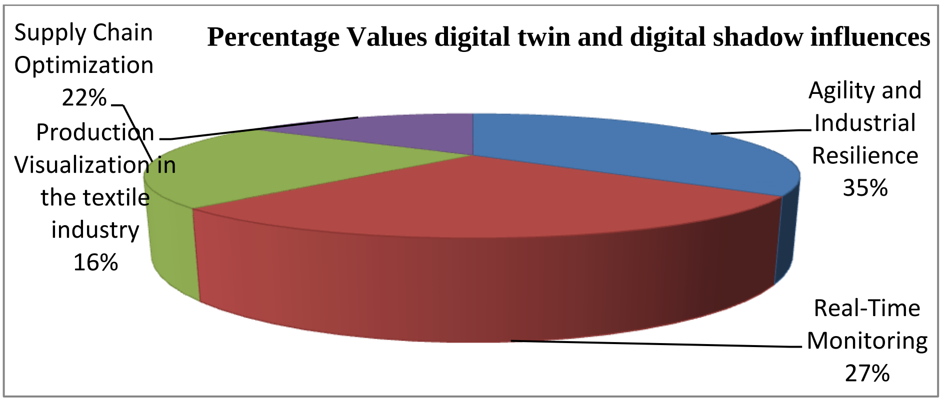

Figure.9. Percentage value of digital twin and digital shadow influences with various PI

The graphical results show the above, with various performance indicators, including agility and industrial resilience, real-time monitoring, supply chain optimization, and production visualization in the textile industry, have been directly and positively influenced by the adoption and application of digital twin and digital shadow strategies. This variable highly improves the overall performance of the manufacturing industries and is used as a catalyst for production virtualization and resiliency. Our findings provide insights into developing and using effective and efficient digital twin and digital shadow approaches for manufacturing industry virtualization, resilience, and inclusive developments. In digital manufacturing, digital twins are a production approach that permits the economical creation of varied work material in visible and repeatable collections and systems. With the application of digital shadow and digital twins as the foundation of the industrial revolution and production resiliencies, it is now simple to empower industries to make data-driven production and business processes.

4.3. Mind Map Analysis

Digital shadow and digital twin technologies aid in the digital transformation of production by connecting previously fragmented systems and processes across the production process and through the supply chain via interactive computer systems and digital environments. Applying digital twin strategies in digital production and the accompanying interconnection segments improves performance, including enhanced production visualization, agility, and industrial resilience, optimizes the supply chain process, and is used as an aid for inclusive developments.

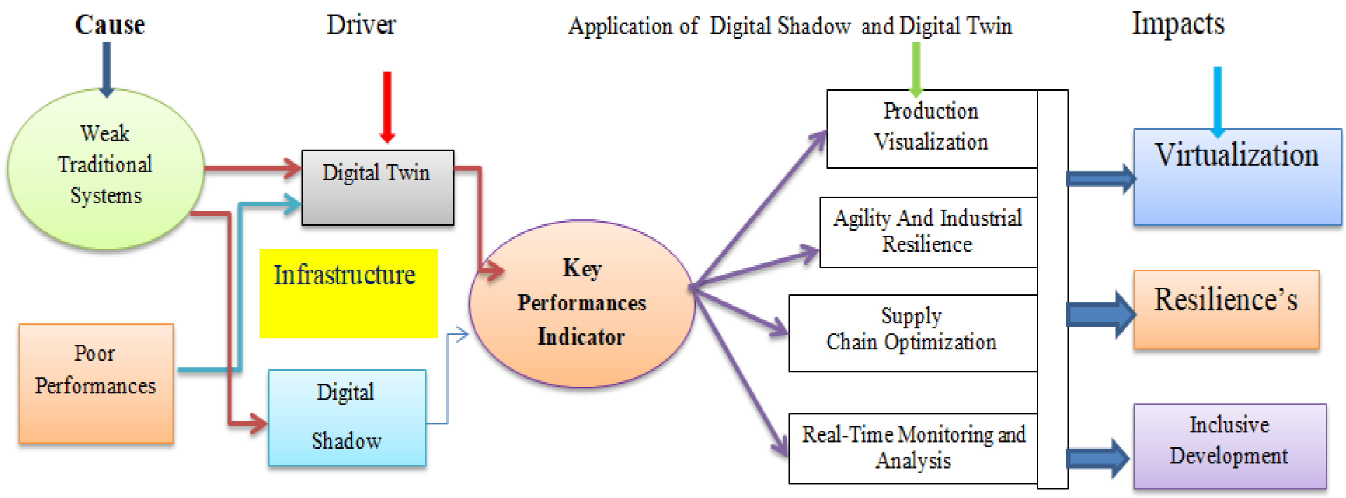

Figure.10. Mind Map analysis and results on the impacts of digital shadow and digital twin

According to this mind map analysis, it shows that due to poor and traditional systems, there was poor industrial performance in the textile and apparel industry. But the adoption and application of both digital shadow and digital twin strategies provide to improve manufacturing industries to higher extents. This implies that well-organized digital infrastructure was used as a catalyst for production virtualization, industrial resilience, supply chain optimization, and real data monitoring processes in the manufacturing industries. In essence, the role of digital shadow and digital twins in manufacturing represents a paradigm shift, transforming creativity into an agile, flexible, dynamic, and collaborative process. Also, our mind map analysis shows that supply chain optimization through digital shadow and digital twins involves agile ordering, raw material supplies, and production workflows to achieve optimal results throughout the supply chain process. Finally, agile, improved, and optimal digital twin and digital shadow applications impact virtualization, supply chain resilience, and inclusive developments of manufacturing industries in general. Thus, firms use digital shadow and digital twin technologies for integrating the manufacturing industry within and across the supply chain, exploring seamless integration of digital and digital twins across design, product development, innovation, manufacturing, raw material, distribution, and customer handling processes. . Therefore, manufacturing industries provide consideration of digital shadows and digital twins in production and supply chain processes. Implementing them is the key component, and the benefits they bring are improved production processes, supply chain optimization, real-time data processes, visibility, and collaboration in the textile industries.

5. CONCLUSION AND IMPLICATION

5.1. Conclusion

The developing digitalization technologies have the potential to improved agile and flexible , visualized production systems. Digitalisation including digital twin and digital shadow benefits are numerous, ranging from greater industrial efficiency to the placement of innovative production systems and process. The research aimed to increase the depth of understanding regarding the roles of digital shadow and digital twin technologies in the performances of manufacturing industry in general textile sector in particular. The study is designed to addressed the impacts of digital shadow and digital twins infrastructure used as a catalyst for production virtualization and resiliencies in the textile sector. From the above argument, it is concluded that production visualization, real-time monitoring ,supply chain optimization, and agility and industrial resilience are the four indicators for the digital shadow and digital twin roles on the performances of manufacturing industry in general, textile sectors in particular. Consequently, developing digital platforms including digital shadow and digital twin strategies ,should be a headmost concern for manufacturing industries. Those industries first need to expand their overall data acquisition and data analytics abilities to handle the enormous amounts of data generating every day within the digital twin and digital shadow systems , which would require data analysts and scientists with expertise in collecting, refining and analysing data. They also have to be open and willing to share data and information with their partners , raw material suppliers and other segments of the manufacturing industries. Then, they need to protect their data from cyber-attacks that can be detrimental to tasks and negatively affect the brand.

5.2.Managerial Implications

In the current industrial revolution, production processes are more complex, sophisticated production inefficiencies are more common, and keeping pace with regulatory standards and rapid changes in the market is difficult (Mohd Javaid, 2023). This focuses on grass-roots change and will enhance our understanding of collective action and society's engagement by providing case studies based upon the experiences of those who participated in them. Successfully directing these challenges involves an inclusive, integrated, and innovative task for all experts, industry leaders, and stakeholders. This digital shadow and digital twins investigations have play an important role by connecting and collaborating with individuals, expertise, engineering, and productions and creating a digital representation of the manufacturing process for inclusive developments. In Ethiopia, manufacturing industry, services sectors does not easily access global market and leads to reduce performances and competitiveness of at firm and sector wise. This habit has been played a significant effect in in-efficient production, quality, resilience and competitiveness of manufacturing industries at national and global levels. Thus, our digital twin and digital shadow investigations aims to be a catalyst for Ethiopia's socio-economic transformation, paving the way for inclusive and sustainable growth in the global digital economy. The analysis will be useful for the organizations willing to gain a competitive advantage by digitalizing their production process and supply chain segments of the textile sectors.

5.3.Practical Contributions

Digital twin and digital shadow technologies are highly enabling innovation, inclusive development, and sustainability in developing and developed nations. Results will significantly impact the diversification of economic activities, primarily results affecting the textile industries in a global scenario, increasing opportunities for new individuals with high-quality hard and soft digital infrastructure. This study provides to integrate and digitally enhance strategies to significantly overcome the challenges of production-disconnected systems, traditional production, silos of information, lack of collaboration, challenging logistics, impact on quality, and efficiency.

5.4.Theoretical Contributions

The study presented a brief description of the roles of digitalization, digital shadow and digital twin that provide valuable insights into scholars regarding the impact of technological advancements in the manufacturing process and supply chain optimizations and illustrated how these enablers can be helpful in transforming various processes of production systems. An empirical investigations were done for the identified the roles and driving powers of digital shadow and digital twins on manufacturing industry performances that provides the sequence in which the technological enablers should be considered in different levels of the production process. Additionally, this research will add to the body of knowledge on transformation and transformational change, which will be strengthened through creative digital inquiry to explore what populations undergoing change regard as transformative. The analysis will serve as a foundation for practitioners to expand their practices for a successful digital revolution of the textile industries.

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