Digital Twin is a Technological Opportunity for Mega Growth of Indian Business

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Keywords

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Sustainability Management

Abstract

The emergence of the fourth industrial revolution led to autonomy, data exchange, modelling and multitude of technologies. Digital Twin is the vital technology for fourth industrial revolution milestone of cyber-physical systems and DT is transforming business scenario world-wide. The applications of Digital Twin technology are growing rapidly globally and projected to 156 billion USD by 2032. Digital Twin market in India in 2032 is projected to reach 12 billion USD. The research objective of this paper is to gather and review available literature and to examine how Digital Twin technology with fusion of technologies like Cloud computing, IoT, AR/VR, AI can streamline intelligence automation in different industries. The paper brings conceptual understanding of DT, track its evolution, and development, building digital framework, identify key technology enablers and explore potential industry wise and applications wise for high growth of DT in India. This paper using SWOT explores the tremendous opportunities for the growth of Indian industries using DT.

1. INTRODUCTION

Industry 4.0 consisting of smart devices, data storage systems and manufacturing facilities that laid the premises for autonomously exchanging information, generating actions and automated controlling of each other. Industrial Internet of things (IIoT) makes this exchange possible by gathering data, carrying out analyses and optimizing production in industrial applications. Key constituent technologies of Industry 4.0 are Internet of Things (IoT), Cloud Computing, Cognitive Computing and Cyber-Physical Systems (CPS). The traditional approach was to build physical system and enhance it with appropriate tweaks. The newer approach is to design more virtual based system by integrating the unique features, optimizing performance and self-diagnosing potential issues and challenges. Digital Twin (DT) technology enables machine operator in manufacturing to get trained virtually without requiring services of dedicated trainer or simulator.

Gartner survey of 2019 (1,2) revealed that Digital Twin had entered mainstream usage in business 13% implementing IoT with DT and 62% in verge of implementation. Fortune Business Insights in May 2024 (3) projected global market size to grow by 39.8% to $259.32 billion by 2032 from the current year 2024 of $17.73 billion. Gartner in 2022 (4) predicted that the global market for digital twin will touch $183 billion by 2031 overcoming the gap in 2026. A vertical market model with base of pre-built functions and corresponding eco-systems has to be developed by business to meet competition. Market Research Future (5) in their India Digital Twin Market Overview, valued Indian market size at USD 0.612 billion in 2022 and projected 39.3% compound growth to USD 12.0 billion. Technological advancements and increased demand for predictive maintenance are the main market drivers anticipated to propel the Digital Twin Market in India. Another organization Grand View Research (6) projected growth of 45.8% between 2024 and 2030.

This research paper is developed by understanding what constitutes the Industry 4.0, how technologies like Digital twin shaping this revolution. This was based on literature review of various articles from journals, research papers, survey reports, conference publications, industry publications and use cases of successful applications by leading Digital Twin companies of the world. The following are the sections of this research paper:

1. Introduction
2. Literature Review on background of DT
3. Technologies spurring Digital Twin
4. Some Industry applications of India for potential growth by deploying Digital Twin
5. SWOT analysis of Digital Twin for Indian Industries
6. Summary and Recommendations
7. Conclusion
8. References

2. LITERATURE REVIEW

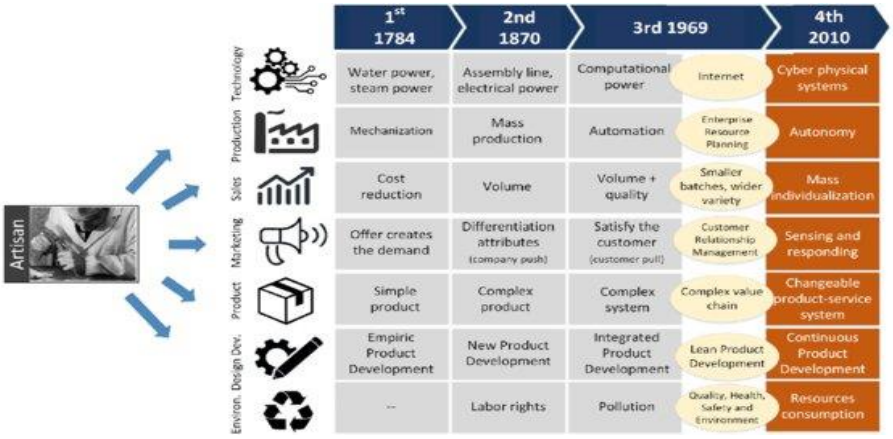
"Digital twins are the next frontier in predictive analytics - IBM Corporation". This was the quote that formed the basis of this research paper.

Information environment for any industrial enterprise is based upon continuous and rigorous collection of data followed by in-depth analysis of data and finally synthesizing into effective parameter modelling. Parameters formulated by modelling can be further engineered into process modelling by applying digital transformation, which can accentuate into a Digital twin model. DT platform consists of both system analytics and predictive analytics parameters. System analytics enable accurate simulation of the physical entity thereby providing consistent assessment of the production rate/state in real-time and helps in optimizing costs while developing a new product. Predictive analytics enable optimal operating conditions of the physical entity, build technological process scenarios in identification of breakdowns and forecast deviations and failures.

Authors of this paper looked at the various literature of the system analytics, predictive analytics and the technologies that provided the platform for Digital twin model. Authors studied the market size and segments internationally and focused on the Indian DT market. India is silently making foray into digital transformation though the applications are confined to more profitable industry segments. Authors feel that there is dire need for using this as technological opportunity for growth in Indian business. This resulted into building SWOT analysis. However, this is only a start and more research and initiatives are to be done on continuous basis.

Industry 4.0 (4IR) in manufacturing or distribution was the period consisting of smart devices, data storage systems and manufacturing facilities that laid the premises for autonomously exchanging information, generating actions and automated controlling of each other. Automation was the main focus for Production in 3IR moving from mechanization and mass production from earlier industrial revolutions. However, with advent of ERP (Enterprises Resources Planning) implementations, it moved to Autonomy in 4IR thereby heralding cognitive ability (Fig 1).

Fig 1 Industry Revolution 1.0 to 4.0



Source: "Research in Engineering Design April 2020"

Digital Twin

Physical twin was the antecedent to Digital Twin and the earliest application developed by NASA in 1969-70s for Apollo space program (8). NASA built couple identical space vehicles, sent a vehicle to space and kept the other vehicle on earth and called it as the Twin. The physical twin model was deployed as simulator by mirroring the precise in-flight conditions of the space vehicle and assisting the on board astronauts with the alternatives. The purpose of the twin is to prototype the space craft and simulate the operational conditions of the spacecraft (9). NASA saved three astronauts lives of failed Apollo 13 Mission in 1970 by remedying the electrical system of the space module by mirroring it with the physical twin (10). NASA in last 50 years from Moon mission to Mars mission is using DT for building digital models of physical systems, components and accessories.

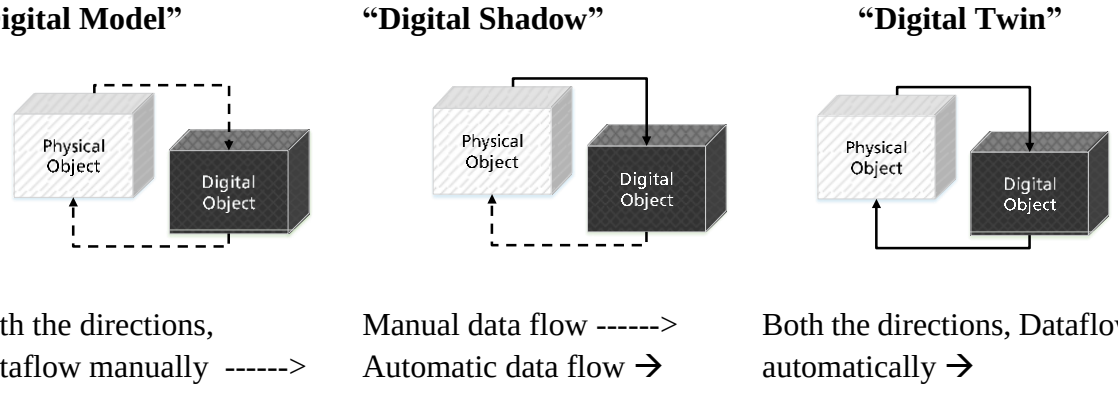
Dr. Michael Grieves conceived the concept of Digital Twin in 2003, “as a digital information construct of the physical system in product life-cycle management, which optimally includes all the relevant information required to complete the task at hand and is linked with the physical system in question” (11). ‘‘The Digital Twin is a representation of an active unique ‘‘product’’ which can be a real device, object, machine, service, intangible asset, or a system consisting of a product and its related services’’ as defined in Production Engineering encyclopedia [12]. In general, “the Digital Twin is defined as virtual representations of physical objects across the product lifecycle management (PLM) that can be understood, learned, and reasoned with real-time data or a simulation model that acquires data from the field and triggers the operation of physical devices” [13,14].

Levels of integration of Digital Twin.

DT was defined in manufacturing excellence as “convergence between the physical and virtual products” (15,16) whereas it was also construed as “real-time digital representation of a physical object” in design-manufacturing (17). Virtual digital modelling representations like “Digital Model, Digital Shadow and Digital Twin” are termed interchangeably. Digital object is connected to physical object by levels of real-time data exchange. However, each of the digital modelling representations is different based on automated exchange of data between the physical object and digital object. “Digital Model” does not have any automated data exchange between the objects. “Digital Shadow “has an automated data flow only between the physical and digital objects. “Digital Twin” is christened due to automated two-way data flows between the physical and digital objects. Any change in state either of the physical object or the digital object will initiate change in other (18).

Fig 2 depicts the data exchanges between physical and digital objects in different representations.

Fig 2



Compiled by the author from the website of sciencedirect.

Evolution of Business Analytics along with Industrial revolutions.

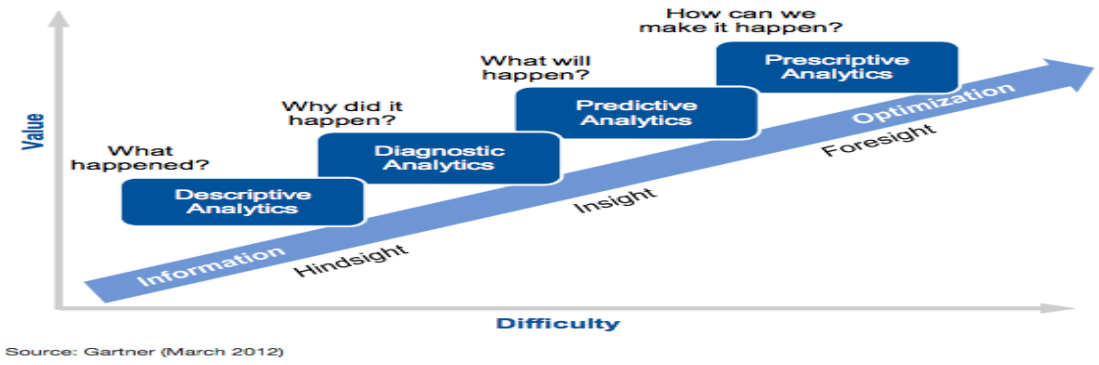
The earlier two IRs was primarily into in collection of the data and transformation of it into reports and later full-fledged management information systems.

Data management was mostly offline. In the later IRs the deployment of new technologies and online mode, led to plethora of information available and consequently led to evolution of data analytics thereby integrating entire operations of business and providing competitive edge. The raw data-to-meaningful information transformation process typically includes collection of data followed by collation and data mining to transform into logical presentations and further analysis. Techniques and tools, such as statistical analysis, data visualization, data modeling and business intelligence are used to extract different trends, patterns, relationships from multi-media data sets and thereby leading to actionable insights of analytics.

With the valuable information and insights gained from data sourced or generated, business institutions can optimize the information into detailed analysis for better decision making and develop competitive advantage.

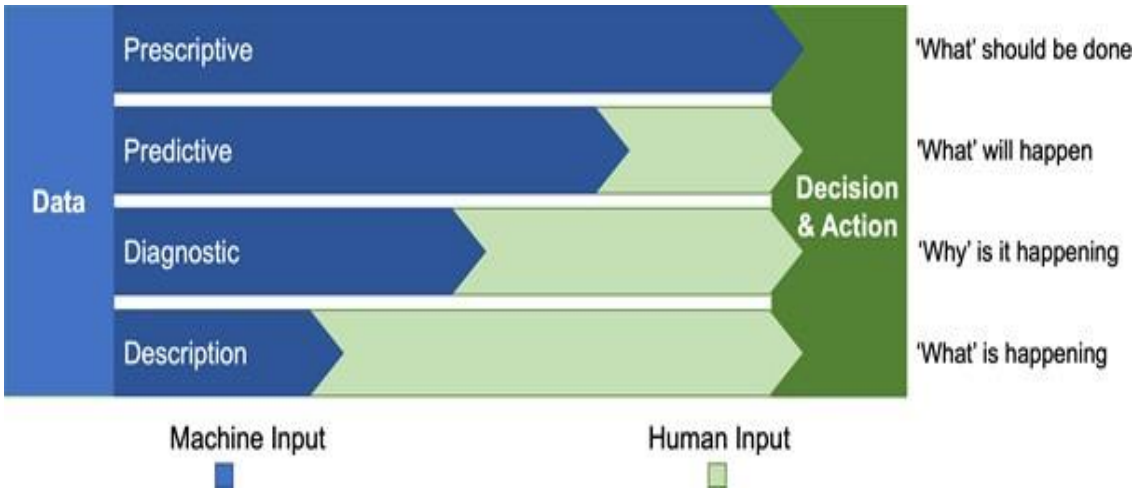
Gartner (19) ascendancy analytics model classified business analytics into four types namely "descriptive (what happened past & now), diagnostic (why it happened), predictive (what likely will happen in future) and prescriptive (what should be done about it)". It paved information gained from hindsight and use insights for analyzing future valuable decision making through foresight (Fig 3).

Fig 3



The taxonomy provided by Gartner can be the framework for Digital Twin implementation (20) for making better decisions. Machine and Human inputs are required for each type of analytical situations of Digital Twin framework. Human can use this information to make decisions by using both machine and human data inputs into actionable decisions (Fig 4).

Fig 4 (Source: Gartner)



3. TECHNOLOGIES SPURRING DIGITAL TWIN

Levels of integration of data exchange are based on acquiring data, modelling the data and applying the data (21). The combination of technologies needed for the DT application are different due to the difference in the applications and varying levels of data integration. The rapid growth and worldwide usage of IoT have made the Digital Twins cost-effective and highly accessible for the business world.

Business world-wide uses different simulation models and methods, different communication protocols and core IR 4.0 technologies like AI/ML (Artificial Intelligence / Machine Learning), cloud computing, IoT, Big data and Extended reality etc. These technology enablers are spurring DT implementations.

- Cloud computing provides hosted services over internet totally scalable and flexible infrastructure of data computation and data storage for digital twin implementations (22). Cloud computing not only gives accessibility to business, but provide powerful computing capabilities at a better cost. Digital Twin is enabled by cloud computing to effectively reduce the time for computation time of complex systems as well as optimize data storage [23].
- Internet of Things (IoT) ensures connection and control of billions of devices on the network using the internet protocol. Digital twin built on IoT sensors is a virtual representation of the "physical product/asset/process" that is digitized and simulated as twin model. Data and information can travel between IoT devices and the virtual simulation platform using IoT Digital thread (24).
- Amazon Inc. defines "Artificial intelligence (AI) is the field of computer science that's dedicated to solving cognitive problems commonly associated with human intelligence, such as learning, problem solving, and pattern recognition (25)". Machine learning is an AI technique that is used for building statistical models and algorithms, by inferring on patterns without explicit programming instructions for the computers. AI/ML can assist DT with cognitive ability using different types of analytics thereby creating outcomes to prevent potential problems.
- Big Data is vast range of data acquired from disparate sources of machines, physical assets, social media and transactions and kept in multiple formats. To gain insights from the big data, iteration cycles of generating, parsing, combining and filtering to be done to provide analytical scenario. Big data generates valuable information and Digital twin provides the optimal analyzation (26) for the intended industrial application.
- Extended reality technology termed as XR is the combination of Virtual Reality (VR) & Augmented Reality (AR) technologies. XR in real-time conditions, create the digital representations of physical object and virtual object (27). Digital Twins utilize XR capabilities and provides users for interacting with physical model using digital data.

4. SOME INDUSTRY APPLICATIONS OF INDIA FOR POTENTIAL GROWTH BY DEPLOYING DT

The significant growth of Digital twin market in India is due to (a) rapid adoption of cloud-based solutions and services, (b) increasing demand for big-data analytics and (c) wider reach of AI thereby enabling digital platform for business and customers.

The growing deployment of cloud-based solutions, rising demand for big data analytics, and increasing implementation of AI in digital experience platforms have significantly propelled the growth of the India digital twin market. The table 1 below shows the application and industry based segments for Digital twin market in India.

Table 1 – "Application and Industry segments for DT in India"

Application Segment for Digital Twin in India	**Industry Segment for Digital Twin in India**	
Product Design & Development	Agriculture	Infrastructure
Predictive Maintenance	Aerospace	Oil & Gas
Performance Monitoring	Automotive & Transportation	Telecom
Business Optimization	Construction	Retail
Inventory Management	Energy & Utilities	Smart Cities/ Towns / Farming
Smart Technology	Healthcare & Life Sciences	Supply Chains

Manufacturing: Radical changes are transforming the manufacturing industry due to technology enablers. Manufacturing activities are poised to grow and drastically transform due to high potential usage of DT technology (28, 29). Manufacturing companies currently constrained being more reactive can move up the chain to predictive mode by better product design, improved process design, higher optimization, preventive maintenance, supply chain integration and cross functional collaboration.

Healthcare and Life Sciences: Digital twin along with IOT data, Big data analytics can fuel significant growth in the healthcare sector from cost savings to diagnosis & therapy, preventive treatment, medical devices utilization, drug formulation and clinical research, personalized healthcare, facility layouts and medical education & training. Digital transformation efforts accentuated healthcare sector due to COVID-19 pandemic (30).

Retail: Retail segment has the pulse of the consumer and Digital twin can augment their requirements and experience by creation of the virtual object. DT also provides better merchandising of goods, inventory optimization, supply chain management & optimization, store layout operations, energy management, product inception, design and development, service design and process orientation.

Automobile and Transportation: Digital Twin creates the digital model of a connected vehicle using the data of operations and behavior of the vehicle and by data visualization able to optimize the performance of it. DT is widely embraced in automobile & transportation sector in terms of fleet management, route optimization, design customization, defect detection, weather forecasting and real-time monitoring.

Smart Cities / Towns / Farming: The digital twin model assists the policymakers in the planning and implementation of smart cities / towns by optimization of various resources, reduction of ecological footprint, increase the quality of common citizen**'s** life, better sustainability and economic development.

The data from the DT help policymakers in arriving at informed decisions with regard to future by analyzing the operational and environmental data and modelling for preventive measures and risk mitigation.

Digital Twin technology overall for all industry and application segments of Indian market can offer technological opportunity for mega growth of business. DT brings in unprecedented efficiency in terms of cost, time, sustainability, safety and complete asset management.

5. SWOT analysis of Digital Twin for Indian Industries

The adoption of DT technology and successful implementations worldwide provides very optimistic scenario for the Indian industry. The projections by various survey companies signifies the mega growth technological opportunity for Indian business using Digital twin. One needs to introspect further on the role of DT for Indian business and realistic view of the Indian business landscape should be studied extensively underlying the internal factors of strengths & weakness and external factors of opportunities and threats. The summary of SWOT analysis done at the broader level by the authors is detailed below in Fig 5.

Strengths:

Digital twin which incorporates IR 4.0 key technologies of AI, ML, IoT, Big data, XR, cognitive learning and cloud computing is primarily used in industry internet of things, engineering and manufacturing business space. The wide spread usage of sensor networks and intelligence systems have made the Digital Twin more cost-effective, universally available and applicable for business segments. Digitalization is democratizing manufacturing / marketing, bridging the Indian rural urban divide, transcending traditional boundaries and feeding trends and solutions for consumers. Digital Infrastructure in India has propelled the growth of developing economy since digitalization has enabled wider reach, better accessibility, easier adoption, virtual models and process steps. The resulting large datasets are mined, analyzed and examined by simulation and optimization tools. The information insights gained is used for real-time planning (31). Economic reforms in India had led to high level of adoption of global technologies, higher volumes, decreased cost margins and better digital infrastructure. India has the highest young workforce globally, who are getting trained on technical skills, education and work landscape. Young workforce educated & trained in digitalization is spearheading in growth of digital payments and today the small business is ahead of large business in Indian market.

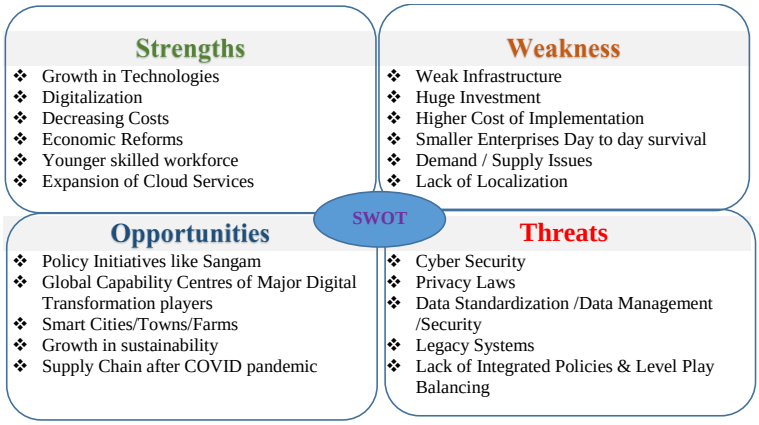
Multinational corporates like Amazon, Google, IBM, Microsoft, Google, Oracle and others are well established in India for implementing global enterprise applications and solutions. These companies are launching Digital Twin virtual environment for building real-time asset monitoring, latest systems and customized solutions. Global Capability Centers established by these corporates are outsourcing to the increasing gig workforce in India.

Weakness:

Infrastructure facilities both physical and social are important for giving fillip to economy, reducing poverty and developing human resources (32). The economic progression of the country hinges on human capital for education, skills and health (33).

Physical infrastructure is crucial in terms of utilities like energy, electricity, water, telecommunication, seaports, information technology and transportation.

Fig 5 – SWOT Analysis for Indian business using DT technology



India as a developing country in spite of significant growth still lags behind the developed and fast developing economies of the world. Physical infrastructure harnessed with social facilities of human capital can provide safety and quality to citizens of the globe (34). To implement digital twin solutions, it requires huge investments in modelling, data collection/creation/storage/maintenance/mining, analytics and finally security.

"The Government of India introduced the term Micro, Small and Medium Enterprise (bodies that are engaged in the manufacturing, production, processing and preservation of goods and commodities and referred as MSMEs) in agreement with the MSMED (Micro, Small and Medium Enterprises Development) Act, 2006". Table below give details of MSMEs in India.

Type of MSMEs	No of enterprises in lakhs	Percentage out of MSMEs
Micro-enterprises	630.50	99.46 %
Small businesses	3.30	0.52%
Medium businesses	0.05	0.01%
Total MSMEs	633.90	

Out of 633.0 MSMEs, around 49% (309 lakh) are in urban and balance 51% (324.9 lakh) are in rural areas.

Digital Twin market in India based on the size of enterprises, can be split into "large enterprises and small and medium-sized enterprises (MSMEs)". The large enterprises of India can afford the huge investments and adoption of technologies and because of it they hold higher market share. Small enterprises segments in spite of contributing 92% industrial production, 42% industry exports, 40% industrial production and highest employment provider are besieged with day to day operational problems in terms of costs, time and efficiency. Digital twin implementation requires a robust and reliable infrastructure including advanced sensors, communication networks and computing power as well as team of experts with specific skills in data analytics, IoT and artificial intelligence.

MSMED enterprise even if the requisite technology is available within their organization, are confronted with operational challenges leading to lack of adoption of new technologies. Another area of concern is most of these technologies need localization. Localization helps in translation and customization of digital applications and the data contents. Localization is required for various digital tools, devices and platforms to enable mass adoption of Digital Twin.

Opportunities:

Any technology planning and implementation requires solid ecosystems of policy support from the nation. Government of India has laid the foundation for a successful digital ecosystem by establishing Digital India (37). This foundation for well-connected India can forge economic growth, citizen empowerment and inclusion. McKinsey Global Institute (36) estimates that by 2025, India's persistence for Digital Platform Infrastructure (DPI) could add $1 trillion to India GDP. India Stack set of interoperable digital platforms constitute DPI and some of the renowned applications from it like UPI, BHIM, Aadhaar and ONDC etc. are successful in bridging the digital and rural urban divides, thereby providing immense opportunity in digital spheres. Department of Telecommunications (DoT) has initiated "Sangam: Digital Twin" for massive restructuring of infrastructure planning and design, by fusion of next-generation computational technologies. Global capability centers, also known as GCCs are global companies in India and are spread across sectors including technology, engineering, consulting and many more. India has 1800 GCCs employing 1.3 million Indians and has become most preferred Innovation Hubs due to high talent, skill, cost effectiveness and Government support. World famous companies implementing Digital Twin in world market have their GCCs in India. Indian industries like manufacturing, retail, automobile and aviation, smart companies, healthcare, telecommunication and energy can propel DT market in India.

India's by 2030 requires an addition of around 44 GW annually to achieve its target of reaching 500GW renewable capacity. This target amounts to 190-215 billion USD as per report of Economic Times, 17 June 2024. India is emerging force in sustainability management and to pitch fork into front liner, conducive private and public investments are mandatory with appropriate eco-systems and continuous skills training and education. Covid19 pandemic has transformed the skilled workforce requirement and enabled organizations to tap into GIG talent workforce. "According to NASSCOM report, India's technology gig workforce is projected to reach 23.5 million in 2030 against 7 million in 2023 and it terms of percentage 4.1% of total in year 2030 against 1.5% in 2022". GCCs are the major seekers of gig workforce and India is poised for growth in deployment of the same. ET June 2024 quotes Randstad projection of 70,000 gig professionals are required within next 6 months for GCCs setup in India.

Threats:

Digital twin technology collects data from multiple avenues and media which includes devices, sensors, equipment and databases. These diverse sources data have to be collected, collated, mined and then integrated. This can be really challenging and without integration all digital twin modes may not provide right insights and foresights required for predictions. Data privacy and Cybersecurity are significant concerns world-wide specifically more with India.

Data breaches, cyberattacks, lack of stringent privacy violations etc. makes it difficult to provide critical data and ensure the security. There is lack of infrastructure that India lacks and resultant DT implementation costs are significantly higher than competition. There is shortage of skilled professionals that can hinder adoption of DT. Huge investment required for education, training and localization of DT technology for young workforce of India. Legacy platforms and applications are widely used in India where there is urgent transformation required to get into open technologies to benefit from DT implementations.

6. Summary and Recommendations

Fourth industrial revolution due to emergence of digital technologies led to more computing power, cheaper and mega storage systems, higher band-width, global connectivity and higher accessibility to all. Digital technologies enabled access to real-time data and easier integration of physical and digital worlds. Digital twin technology brings in seamless integration between physical and virtual objects with automatic dataflow in both the directions. Physical twin was initially used as a simulator for aviation experimentation. Physical asset or process constitutes the real data, digital model comprises the abstraction of the asset, real- time data provides the knowledge and analytics gives intelligence thereby entire Digital Twin enable an information life cycle of build & model, connect & collect, analyze, execute & optimize, innovate and back to build. Digital Technologies advances and adoptions spurred the DT integration in many applications and industrial segments. The need for automation and precision in various Indian industries is triggering the demand for DT platform and from manufacturing automation the trend has moved to autonomy that provides cognitive ability. Fifth industrial revolution is more about human-centric approach towards manufacturing process.

Due to good digital infrastructure, Indian consumers are surging ahead whereas adoption is uneven in business and gap dividing the digital leaders and other organizations. The adoption of digital technologies and implementation of applications both by the public and private sectors of India stimulating the economic growth. IT, BPO, KPO, digital media, electronics manufacturing & export are core domains where digital applications are extensively used in India. It is expected to double their GDP level to $355-435 billion in 2025. Other sectors like agriculture, education, energy, financial services, healthcare, logistics, and retail, government and recruitment services can be the new domains for digitalization and this can generate additional $10-150 billion economic value in 2025. This can be the growing technological opportunity for Digital Twin. To get a realistic picture of the Indian landscape for Digital twin, SWOT analysis was done and details explained.

7. CONCLUSION

Policies and ease of business should be accommodative and at the same time channelize into the Indian markets. Technology companies must adopt sustainable practices to mitigate environmental impact, enhance energy efficiency and promote a circular economy by designing products for longevity, repair ability and renewability for a greener future. Huge investment required for education, skill building and localization of DT technology for young workforce of India. In addition to building digital infrastructure, core social and physical infrastructure to be enhanced to bring down the costs and face competition.

Manufacturing, healthcare, automobile & transportation, retail and smart cities will propel the growth of DT in India due to huge customer base and both private and public participation. However, agriculture, energy and telecommunications which are huge areas for DT implementation require huge backing and investments from the government.

Digital Twin technology should revolutionize Indian business landscape and provide betterment for humankind. Private and Public sectors to work in unison in building effective ecosystems for growth of Indian business using Digital Twin platform thereby eliminating the need for examining the physical system.

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8. REFERENCES

1. Gartner, Gartner survey reveals digital twins are entering mainstream use, 2019, Online: https://www.gartner.com/en/newsroom/press-releases/2019-02-20-gartner-survey-reveals-digital-twins-are-entering-mai
2. Gartner, Gartner survey reveals digital twins are entering mainstream use, 2019, Online: https://www.gartner.com/en/newsroom/press-releases/2019-02-20-gartner-survey-reveals-digital-twins-are-entering-mai
3. Digital Twin Market size, Share & Industry Analysis. Online: https://www.fortunebusinessinsights.com/digital-twin-market-106246
4. Gartner Research Emerging Technologies: Revenue Opportunity Projection of Digital Twins. Online: https://www.gartner.com/en/documents/4011590
5. India Digital Twin Market Research Report: Source: https://www.marketresearchfuture.com/reports/india-digital-twin-market-21441#download.pdf.
6. Digital Twin Market Size, Share and Growth Report, 2030. Online: https://www.grandviewresearch.com/industry-analysis/digital-twin-market#:~:text=Digital%20twin%20market%20in%20india,the%20India%20digital%20twin%20market.
7. Pereira Pessôa, M.V., Jauregui Becker, J.M. Smart design engineering: a literature review of the impact of the 4th industrial revolution on product design and development. Res Eng Design 31, 175–195 (2020). https://doi.org/10.1007/s00163-020-00330-z
8. Schleich, Benjamin, Nabil Anwer, Luc Mathieu, and Sandro Wartzack. 2017. “Shaping the Digital Twin for Design and Production Engineering.” CIRP Annals 66 (1): 141–44. https://doi.org/10.1016/j.cirp.2017.04.040.
9. Ashwin Agrawal, M.S.1; Martin Fischer, Ph.D.2; Vishal Singh, Ph.D.3 - Digital Twin: From Concept to Practice. https://doi.org/10.1061/(ASCE)ME.1943-5479.0001034.
10. J. Uri, 50 Years ago: Houston, we've had a problem, 2020. Online: https: //www.nasa.gov/feature/50-years-ago-houston-we-ve-had-a-problem.

11. Grieves, Michael, and John Vickers. 2017. “Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems.” In Transdisciplinary Perspectives on Complex Systems: New Findings and Approaches, edited by Franz-Josef Kahlen, Shannon Flumerfelt, and Anabela Alves, 85–113. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-38756-7_4.
12. R. Stark, T. Damerau, Digital twin. The international academy for production engineering, in: S. Chatti, T. Tolio (Eds.), CIRP Encyclopedia of Production Engineering, Springer, Berlin Heidelberg, 2019, pp. 1-8.
13. R.N. Bolton, J.R. Mccoll-Kennedy, L. Cheung, Customer experience challenges: bringing together digital, physical and social realms, J. Serv. Manag. 29 (5) (2018) 776-808.
14. N. Negri, S. Berardi, S. Fumagalli, MES-integrated digital twin frameworks, J. Manuf. Syst. 56 (2020) 58-71.
15. M. Grieves, Digital Twin: Manufacturing Excellence Through Virtual Factory Replication, White Paper, 2014, pp. 1-7, Online: https://www.researchgate.net/publication/275211047_Digital_Twin_Manufacturing_Excellence_through_Virtual_Factory_Replication.
16. F. Tao, F.Y. Sui, A. Liu, Digital twin-driven product design framework, Int. J. Prod. Res. 57 (12) (2019) 3935-3953.
17. Y. Fu, G. Zhu, M. Zhu, et al., Digital twin for integration of design-manufacturing-maintenance: An overview, Chin. J. Mech. Eng. 35 (80) (2022). http://dx.doi.org/10.1186/s10033-022-00760-x, 2022.
18. W. Kritzinger, M. Karner, G. Traar, J. Henjes, W. Sihn, Digital twin in manufacturing: A categorical literature review and classification, IFAC-PapersOnLine 51 (11) (2018) 1016-1022.
19. Gartner. 2013. “Extend Your Portfolio of Analytics Capabilities.” Gartner. 2013. https://www.gartner.com/en/documents/2594822/extend-your-portfolio-of-analytics-capabilities.
20. Ashwin Agrawal, M.S.1; Martin Fischer, Ph.D.2; Vishal Singh, Ph.D.3 - Digital Twin: From Concept to Practice. https://doi.org/10.1061/(ASCE)ME.1943-5479.0001034.
21. Lv Z and Xie S. Artificial intelligence in the digital twins: State of the art, challenges, and future research topics [version 2; peer review: 2 approved]. Digital Twin 2022, 1:12 (https://doi.org/10.12688/digitaltwin.17524.2)
22. M. Attaran, The Internet of Things: Limitless opportunities for business and society, J. Strateg. Innov. Sustain. 12 (1) (2017).
23. Z. Shu, J. Wan, D. Zhang, Cloud-integrated cyber-physical systems for complex industrial applications, Mob. Netw. Appl. 21 (5) (2016) 865-878.
24. Carlos Miskinis Comparing the internet of things vs digital twin. Online: https://www.challenge.org/insights/internet-of-things-vs-digital-twin/
25. Amazon on AI/ML and Digital Twin. https://aws.amazon.com/what-is/digital-twin/#:~:text=Digital%20twin%20technology%20uses%20machine,%2C%20emissions%20outputs%2C%20and%20efficiencies.
26. M. Callista and H. Tjahyadi, "Digital Twin and Big Data in Healthcare," 2022 1st International Conference on Technology Innovation and Its Applications (ICTIIA), Tangerang, Indonesia, 2022, pp. 1-4, doi: 10.1109/ICTIIA54654.2022.9935847.

27. B. Marr, What is extended reality technology? A simple explanation for anyone. Aug 12, 2019, 2019, Online: https://www.forbes.com/sites/bernardmarr/ 2019/08/12/what-is-extended-reality-technology-a-simple-explanation-for- anyone/? sh=22e4c7117249.
28. A. Bilberg, A.A. Malik, Digital twin driven human-robot collaborative assembly, CIRP Ann. 68 (2019) 499-502.
29. B. Tekinerdogan, C. Verdouw, Systems architecture design pattern catalog for developing digital twins, Sensors 20 (2020) 5103.
30. Global Market Insight, Digital twin market. Online, 2022, https://www. gminsights.com/industry-analysis/digital-twin-market.
31. Boschert, Stefan; Rosen, Roland (2016). Digital Twin—The Simulation Aspect. In Peter Hehenberger, David Bradley (Eds.): Mechatronic Futures. Cham: Springer International Publishing, pp. 59–74.
32. Pradeep Agarwal - Infrastructure in India: Challenges and the Way Ahead, IEG Working Paper No. 350, 2015. Online: https://iegindia.org/upload/publication/Workpap/wp350.pdf.
33. Hanushek, E. A. and Woessmann, L. 2008. 'The Role of Cognitive Skills in Economic Development'. Journal of Economic Literature 607-68.
34. Estache, A. 2006. 'Infrastructure: A Survey of Recent and Upcoming Issues'. In World Bank ABCDE Conference Tokyo, 29-30).
35. Forbes India. Online:- https://www.forbes.com/advisor/in/business/msme-statistics/
36. McKinsey Global Institute (2022) - Digital-India-technology-to-transform-a-connected-nation-Full-report
37. Aditi Maheshwari article on India's digital journey takes flight in TOI (13 Feb 2024)
38. Jones Lang LaSalle (JLL) Research Report on Global Capability Centers in India, Feb 2024. https://www.jll.co.in/en/trends-and-insights/research/the-rise-of-global-capabilities-centres-in-india
39. Economic Times report on Global capability centres go big on hiring gig employees. https://economictimes.indiatimes.com/jobs/hr-policies-trends/global-capability-centres-go-big-on-hiring-gig-employees/articleshow/110603734.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst
40. THE RISE OF GIG ECONOMY IN INDIA NASSCOM AON report quoted by Times of India. https://timesofindia.indiatimes.com/city/bengaluru/tech-gig-economy-grows-india-to-have-23-5-million-workers-by-2030/articleshow/111048791.cms.