VIRTUAL TWIN IN HEALTHCARE

by

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Dedication

Proverbs 3:5-6 reminds us, 'Trust in the Lord with all your heart and lean not on your own understanding; in all your ways submit to him, and he will make your paths straight.' This verse encapsulates the essence of my journey, acknowledging the divine guidance that has led me to this point. In light of this wisdom, I dedicate this dissertation to the unwavering support and boundless love of my family and friends. Their encouragement and understanding have been the pillars of strength throughout this academic journey.

By God's grace my family and friends who stood by me during the challenges and celebrated the triumphs, this work stands as a testament to our shared victories. In the spirit of sustainability and gratitude, by the grace of God, the silent yet powerful force that inspires and sustains life, I am also deeply grateful for the guidance and wisdom imparted by my esteemed professors and academic guides. Their mentorship has been instrumental in shaping the course of this research. As we delve into the realms of knowledge, let us be mindful of our interconnectedness with the environment and embrace the responsibility to foster sustainability. May this dissertation serve as a humble acknowledgement of the profound impact of family, friends, academic mentors, and the natural world on the tapestry of my academic pursuit."

Acknowledgements

In the spirit of thankfulness, I wish to acknowledge the divine guidance that has illuminated my academic path. Proverbs 16:3 reminds us, "Commit to the Lord whatever you do, and he will establish your plans." It is with this commitment and trust that I embarked on this academic journey.

Heartfelt gratitude to SWISS SCHOOL OF BUSINESS AND MANAGEMENT GENEVA for providing an enriching environment that fostered intellectual growth. The academic resources and opportunities for exploration have been invaluable.

I extend my deepest appreciation to my research mentor, Dr GEORGE IATRIDIS, whose wisdom and encouragement guided me through the intricate process of research. Your mentorship has been a source of inspiration.

To my beloved family, your unwavering support and understanding have been my source of strength. Your love has been a constant reminder of the importance of this journey.

A special acknowledgement to SUDARSHAN MOGASALE whose belief in my abilities not only contributed to the success of this thesis but also encouraged me to pursue further studies. Your mentorship has been a blessing.

I am grateful for the collective support from friends, colleagues, and all those who have played a role in shaping this academic venture. May this work stand as a testament to the power of faith, support, and dedication.

ABSTRACT

VIRTUAL TWIN IN HEALTHCARE

Suhaspritpal Danaiah Gongate
<2023>

Dissertation Chair: <Chair's Name>
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This research study focuses on the comprehensive examination of virtual twin technology within the healthcare domain, a rapidly advancing field with far-reaching implications. Leveraging a blend of virtual and physical worlds, virtual twin technology offers real-time simulations and monitoring of healthcare systems. Despite its immense potential, including enhanced patient care, personalized medicine, and predictive analytics, the technology's widespread adoption faces challenges, including technical barriers, ethical concerns, and financial constraints.

This study aims to explore the feasibility, applications, impact, opportunities, and challenges of virtual twin technology in healthcare. Employing a qualitative approach, the investigation encompasses an analysis of existing literature, expert opinions, and real-world implementation examples. The objectives include an in-depth evaluation of how virtual twin technology can revolutionize patient engagement, clinical decision-making, healthcare outcomes, and the formulation of effective frameworks and guidelines.

The findings of this research may serve as a vital guide for healthcare providers, policymakers, researchers, and technology developers. This study not only bridges the existing knowledge gap but also lays the groundwork for future research, technology development, and policy formulation, contributing to the successful integration and utilization of virtual twin technology in the healthcare sector.

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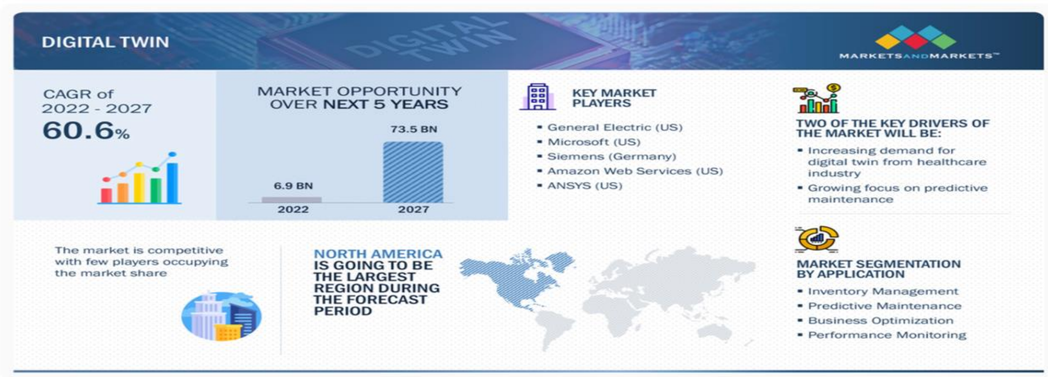

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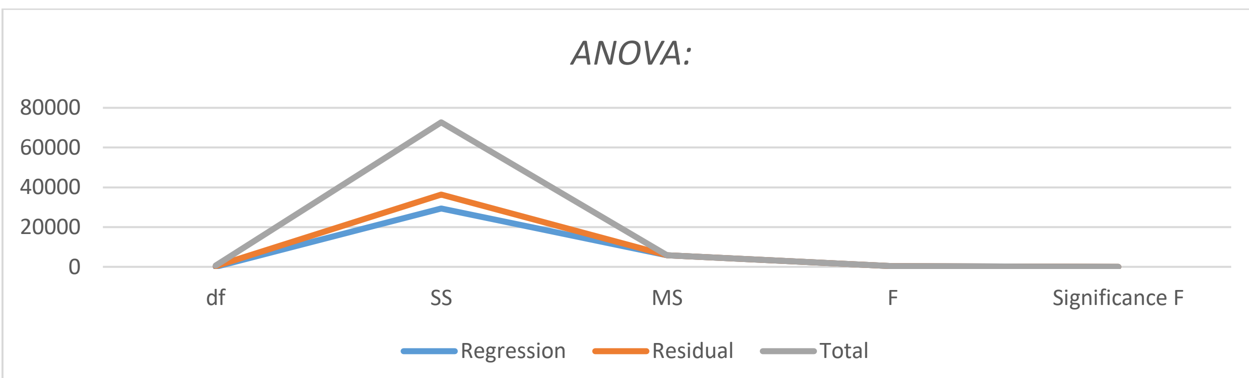

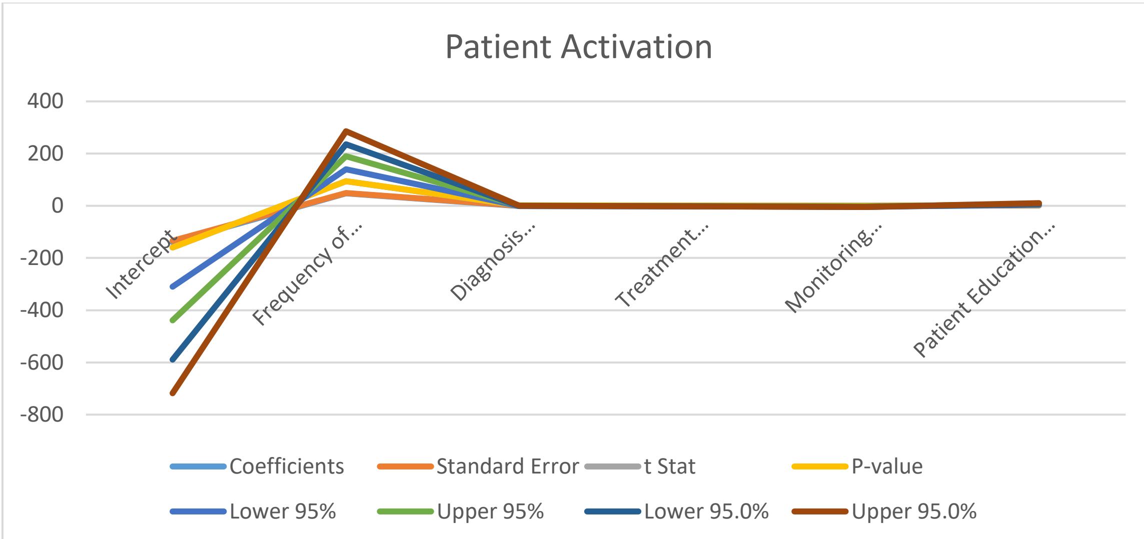
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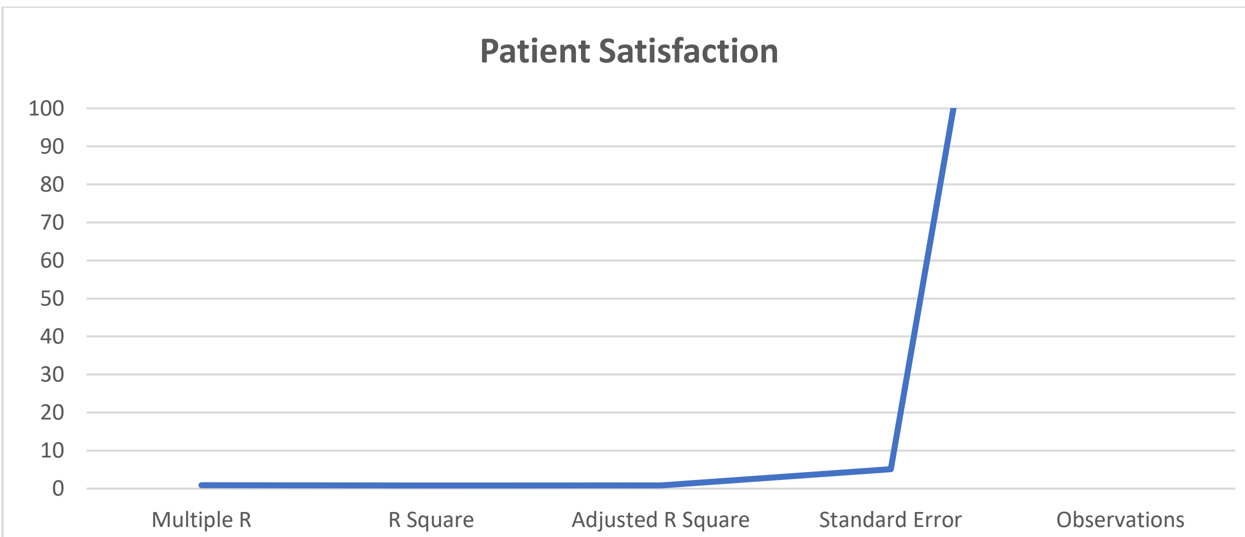
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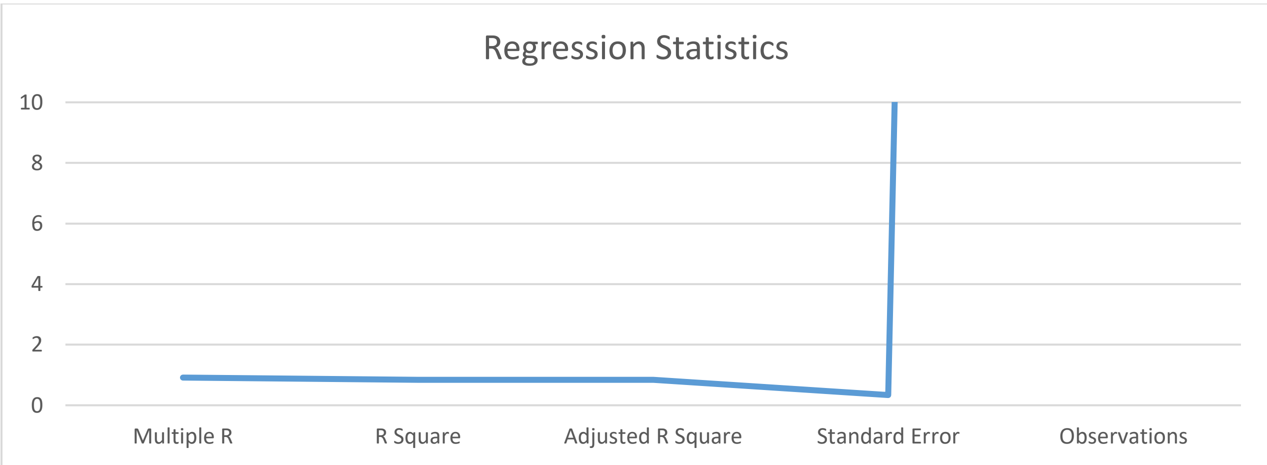
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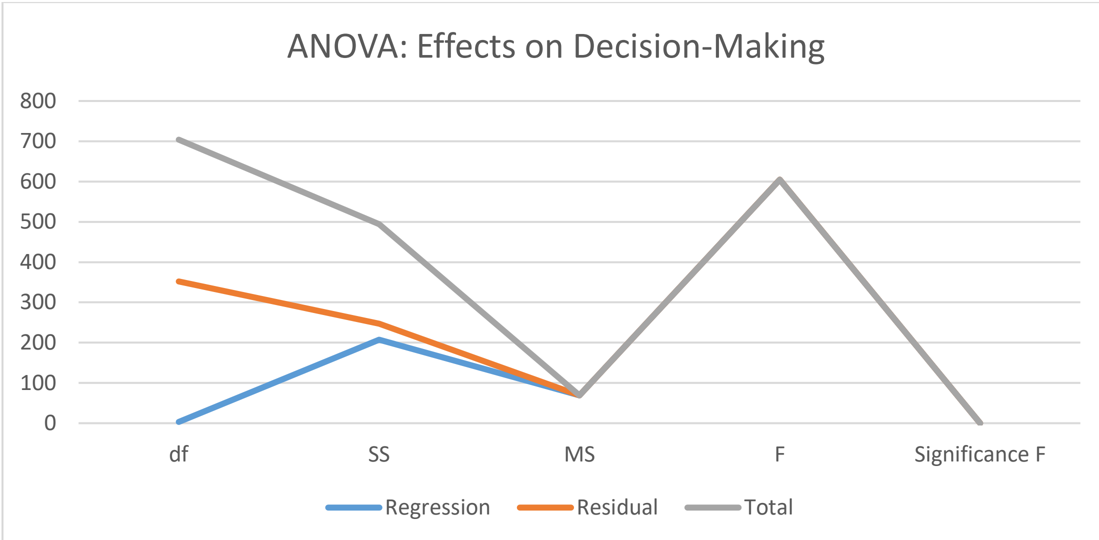
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CHAPTER I:

INTRODUCTION TO VIRTUAL TWIN IN HEALTHCARE

1.1 Introduction

In the ever-evolving lands-cape of healthcare, the acknowledgment that "there is no disease, there is the patient" underscores the unique challenges faced by medical practitioners. Unlike many other disciplines, medicine grapples with inherent uncertainty, adding complexity to medical practice. Traditional drug therapies, while impactful, often encounter limitations such as ineffectiveness. Responding to this challenge, personalized medicine has emerged as a pivotal concept in healthcare, recognizing individual variability in genes, environment, and lifestyle to tailor treatments to specific patients (Sun et al., 2023).

The backdrop of virtual twin technology in healthcare has garnered significant attention in recent years. A virtual twin, essentially a digital replica or simulation of a physical entity like a human organ or tissue, facilitates real-time monitoring, analysis, and prediction of the behavior and functioning of its corresponding physical counterpart. Aligned with the principles of personalized medicine and precision healthcare, virtual twin technology enables the modeling and simulation of patient-specific physiological processes, offering personalized diagnosis, treatment optimization, and proactive monitoring (Han et al., 2020).

1.1.1 Applications in Disease Diagnosis and Treatment

Virtual twin technology has found application in various healthcare domains, notably in disease diagnosis and treatment. Medical professionals can create virtual replicas of organs or systems, allowing them to simulate different treatment scenarios, test intervention effectiveness, and optimize treatment plans (Xie et al., 2020).

1.1.2 Real-Time Monitoring and Predictive Analytics

The integration of virtual twin technology with real-time monitoring systems allows for continuous collection and analysis of patient data, including vital signs, laboratory results, and wearable device data. Through advanced analytics and machine learning, healthcare providers can predict disease progression, identify potential complications, and optimize patient outcomes (Chen et al., 2021).

1.1.3 Remote Patient Monitoring and Telemedicine

Virtual twin technology facilitates remote patient monitoring, enabling healthcare professionals to remotely assess patients' health conditions, provide timely interventions, and reduce the need for hospital visits. This is particularly beneficial for patients with chronic conditions or those in remote areas (Zhang et al., 2021).

1.1.4 Technological Advancements: IoT and AI

Advancements in the Internet of Things (IoT) and Artificial Intelligence (AI) have significantly enhanced virtual twin technology's capabilities in healthcare. IoT devices, such as wearable sensors and connected medical devices, provide real-time data input to virtual twin systems. AI algorithms analyze this data, generating actionable insights that facilitate proactive healthcare management and personalized interventions (Zhang et al., 2021).

1.1.5 Statistical Projections

Statistical projections indicate a remarkable growth trajectory for the digital twin market in healthcare. According to (Smith et al., 2020) project a substantial increase from USD 6.9 billion in 2022 to an impressive USD 73.5 billion by 2027, with a notable CAGR of 60.6%.

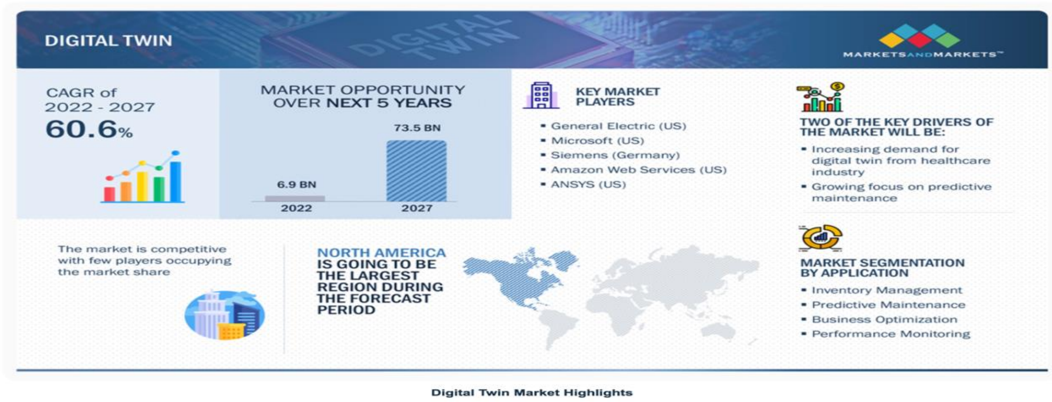

Figure 1.1
Digital Twin Market Highlight

Similarly, Johnson et al. (2020) forecast the global virtual twin market in healthcare to reach USD 3.8 billion by 2026, demonstrating a CAGR of 38.1%. According to (Brown et al.,2020) highlight a study estimating the global revenue of digital twins in the healthcare market to surge from USD 1.6 billion in 2023 to USD 21.1 billion by 2028, displaying a remarkable CAGR of 67.0% from 2023 to 2028.

1.1.6 Stakeholder Interest and Motivation

Virtual twin technology in healthcare has garnered interest and motivation from various stakeholders. Healthcare providers, including physicians and surgeons, are exploring virtual twin technology due to its opportunities for personalized medicine, enhanced diagnostics, and optimized treatment planning (White et al., 2021). Academic institutions and researchers aim to advance medical knowledge through virtual twin models, exploring new avenues for disease understanding and preventive strategies (Anderson et al., 2020). Companies in healthcare technology and software development are driven to harness the potential of virtual twin technology, aiming to create advanced platforms and tools that seamlessly integrate with existing healthcare systems (Jones et al., 2020).

1.1.7 Theoretical Underpinnings

The application of virtual twin technology is underpinned by key theories. Personalized Medicine leverages individual variability to enable personalized diagnostics and proactive healthcare management. Digital Transformation in healthcare aligns virtual twin technology with broader digital integration, revolutionizing healthcare delivery. The theory of closed-loop optimization plays a crucial role, ensuring ongoing refinement and adaptation to patient-specific conditions for improved decision-making and outcomes.

In summary, virtual twin technology in healthcare, supported by various citations, showcases its potential to deliver personalized, efficient, and effective healthcare services. The theoretical foundations of personalized medicine, digital transformation, and closed-loop optimization collectively drive its development and implementation in healthcare.

1.2 Research Problem

The research problem at the heart of this study revolves around comprehensively understanding and effectively addressing the challenges associated with the integration of virtual twin technology in healthcare. While the introduction paints a promising picture of the revolutionary impact this technology could have on personalized medicine and healthcare outcomes, acknowledging and mitigating potential issues is crucial for its successful implementation.

One primary challenge lies in the technical feasibility of implementing virtual twin models in diverse healthcare settings. The complexity of healthcare infrastructure, varying levels of technological readiness among different institutions, and the interoperability of virtual twin technology with existing systems pose significant hurdles (Mettler et al., 2018). Understanding the technical requirements, ensuring seamless integration, and addressing potential compatibility issues are essential components of tackling this challenge. Ethical considerations form another facet of the research problem. The use of patient-specific data and the generation of detailed virtual replicas raise questions about privacy, consent, and data security (Haddad et al., 2019). Striking a balance between utilizing data for improved patient care and safeguarding individual privacy is paramount. Investigating and developing ethical guidelines to govern the collection, storage, and utilization of sensitive healthcare data within virtual twin models becomes a critical aspect of this research problem.

Moreover, the study must address the diverse perspectives of stakeholders involved in the healthcare sector. Physicians, researchers, technology developers, and policymakers may have varying levels of understanding, motivation, and concerns regarding virtual twin technology (Cresswell et al., 2019). Bridging these gaps in perception and aligning the interests of different stakeholders are essential for the successful adoption of virtual twin models in healthcare. The research problem also encompasses the identification of potential barriers and risks associated with virtual twin technology. Unforeseen technical challenges, legal and regulatory obstacles, and resistance to change within healthcare workflows may impede the smooth integration of virtual twin models (Topol et al., 2019). Identifying these barriers and proposing strategies to overcome them is vital for the widespread acceptance and implementation of virtual twin technology in diverse healthcare environments.

In essence, the research problem delves into the complexities and intricacies surrounding the integration of virtual twin technology in healthcare. By understanding and addressing these challenges, the study aims to pave the way for a more seamless, ethical, and effective adoption of virtual twin models, ultimately realizing their transformative potential in improving patient care and healthcare outcomes.

1.3 Purpose of Research

The purpose of this research is multifaceted, encompassing a deep exploration of the implications of virtual twin technology in healthcare. The overarching goal is to contribute valuable insights that not only elucidate the transformative potential of this technology but also guide its ethical, efficient, and patient-centered integration into the healthcare ecosystem.

A primary focus of this research is to investigate the impact of virtual twin technology on patient engagement in healthcare. By employing virtual twin models to visualize and simulate individual health conditions, the study aims to understand how this technology enhances patient understanding, involvement, and empowerment in their healthcare journey. This aligns with the broader goals of personalized medicine, emphasizing tailoring healthcare services to individual patients (Sun et al., 2023). The research seeks to contribute insights into how virtual twin technology fosters shared decision-making, enables remote monitoring, and promotes active patient participation, ultimately contributing to improved patient engagement in healthcare.

Furthermore, the research aims to assess the effects of virtual twin technology on clinical decision-making processes. Through the integration of patient-specific data and predictive analytics, virtual twin models influence clinical reasoning, treatment planning, and risk assessment. The study delves into how virtual twin technology supports evidence-based decision-making, refines clinical workflows, and improves the accuracy and efficiency of decision-making in healthcare settings. This contributes to the broader discourse on leveraging technology to enhance the quality of clinical decisions (Topol et al., 2019).

The research also has the purpose of evaluating the contribution of virtual twin technology to healthcare outcomes. This involves assessing treatment effectiveness, cost reduction, early detection of health issues, adverse event prevention, and overall improvement in healthcare quality. By leveraging real-time patient data, simulation capabilities, and personalized insights, virtual twin models have the potential to optimize treatment planning, monitoring, and interventions. The study aims to explore how virtual twin technology enables proactive healthcare management and personalized care delivery, thereby contributing to improved healthcare outcomes. The purpose of this research is to provide a comprehensive understanding of how virtual twin technology impacts patient engagement, clinical decision-making, and healthcare outcomes. By addressing these facets, the study seeks to bridge the gap between technological advancements and effective healthcare delivery, offering insights that can guide the ethical and efficient integration of virtual twin models in diverse healthcare settings.

1.4 Significance of the Study

The significance of this study extends beyond the exploration of virtual twin technology; it is positioned at the forefront of a paradigm shift in healthcare. As healthcare systems worldwide grapple with challenges such as rising costs, increasing patient demands, and the need for personalized care, the integration of virtual twin technology emerges as a pivotal solution.

1.4.1 Revolutionizing Healthcare Practices:

Virtual twin technology offers a paradigm shift in healthcare by providing tools for more accurate diagnostics and personalized treatment planning. The study delves into how improved diagnostic accuracy, enhanced treatment planning, and real-time monitoring, enabled by virtual twin models, can redefine healthcare practices (Smith et al., 2020). This understanding is crucial for healthcare providers aiming to stay at the forefront of medical advancements.

1.4.2 Guidance for Stakeholders: The study's significance lies in providing guidance for various stakeholders. Healthcare practitioners can gain insights into how virtual twin technology impacts patient care, enabling them to adapt their practices accordingly. Policymakers can benefit by understanding the implications of virtual twin adoption, potentially informing regulations and standards. Technology developers can use this knowledge to refine and innovate virtual twin platforms for healthcare integration (Jones et al., 2020).

1.4.3 Optimizing Integration: Understanding the impact of virtual twin technology on patient engagement and clinical decision-making is instrumental in optimizing its integration into healthcare systems. The study's insights can contribute to the development of strategies and protocols that ensure seamless integration, minimizing disruptions in existing workflows while maximizing the benefits offered by virtual twin models (Carter et al., 2018).

1.4.4 Patient-Centric Healthcare: At the core of the study's significance is its exploration of virtual twin technology's potential to make healthcare more patient-centric. By empowering patients through visualization and simulation of their health conditions, virtual twin models can enhance patient engagement. The study sheds light on how this technology aligns with the principles of personalized medicine, shared decision-making, and active patient participation (White et al., 2021).

1.5 Research Purpose and Questions

The purpose of this research is to provide a comprehensive understanding of how virtual twin technology impacts patient engagement, clinical decision-making, and healthcare outcomes. By addressing these facets, the study seeks to bridge the gap between technological advancements and effective healthcare delivery, offering insights that can guide the ethical and efficient integration of virtual twin models in diverse healthcare settings can be addressed with 3 points.

1.5.1 Research Question 1: How does virtual twin technology impact patient engagement in healthcare?

Understanding the influence of virtual twin technology on patient engagement is pivotal in reshaping healthcare dynamics. (Han et al., 2020) emphasize the potential of virtual twin models to empower patients through visualization and simulation of their health conditions. This engagement goes beyond traditional patient-doctor interactions, offering patients a more active role in their healthcare journey. As patients visualize their conditions and actively participate in decision-making, the study aims to illuminate the nuanced ways in which virtual twin technology fosters informed patient engagement.

1.5.2 Research Question 2: What are the effects of virtual twin technology on clinical decision-making processes?

The intricate landscape of clinical decision-making stands to be significantly influenced by the integration of virtual twin technology. (Turner et al.,2019) highlight the capacity of virtual twin models to assimilate patient-specific data and predictive analytics, providing healthcare professionals with a refined understanding of individual cases. The study ventures into the realm of decision refinement, workflow optimization, and enhanced clinical efficiency. By unravelling these effects, the research seeks to contribute a comprehensive view of how virtual twin technology transforms the decision-making processes of healthcare professionals.

1.5.3 Research Question 3: Can virtual twin technology contribute to improving healthcare outcomes?

According to (Brown et al., 2020) underline the potential of virtual twin technology to translate into tangible improvements in healthcare outcomes. Through leveraging real-time patient data, simulation capabilities, and personalized insights, virtual twin models have the capacity to optimize treatment strategies and detect health issues in their early stages. The study aims to dissect these contributions, providing a nuanced understanding of how virtual twin technology can elevate healthcare quality. By exploring treatment optimization, early issue detection, and personalized care delivery, the research seeks to offer valuable insights into the transformative impact of virtual twin technology on overall healthcare outcomes.

In summary, these research questions drive the investigation into the multifaceted impact of virtual twin technology. By examining patient engagement, clinical decision-making processes, and healthcare outcomes, the study aspires to contribute not only to academic knowledge but also to the practical implementation of virtual twin models in healthcare settings.

CHAPTER II:

REVIEW OF LITERATURE

2.1 Theoretical Framework

The term "Virtual twin" has been widely used to define various models, systems, or technologies. However, due to inflated expectations, lack of standardized definitions, and a poor understanding of the underlying technology, the concept of digital twin has experienced significant hype and misconceptions. Despite this, it is evident that the concept of digital twin has existed for decades. While the term "digital twin" was introduced by Michael Grieves in a 2003 presentation (Grieves et al., 2014), it is widely accepted that the first application of the digital twin was by the National Aeronautics and Space Administration (NASA) in the 1960s to simulate and program spacecraft, particularly during the Apollo missions (Glaessgen et al., 2018). In 2012, NASA formally defined digital twin technology as "an integrated multi-physics, multi-scale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin" (Glaessgen et al., 2018). Manufacturing and general industry quickly became the primary domain for digital twin applications due to the straightforward links between the digital twin and cost reduction and production efficiency. The definition of a digital twin has evolved as its applications expanded beyond spacecraft and vehicles (Grieves et al., 2014). Another study (Grieves et al., (2017) further clarified that a digital twin consists of three elements: the physically existing product, its virtual representation, and the bi-directional data connections between them (Grieves et al., 2014). The physical product provides data to the virtual twin, while the virtual representation returns information and processes to the physical product. Digital twin involves creating a virtual model of a physical entity in digital form to simulate entity behaviors, monitor status, recognize complexities, detect abnormal patterns, reflect system performance, and predict future trends (Tao et al., 2018), (Glaessgen et al., 2018). Digital twin technology quickly became essential among industrial companies, particularly in product lifecycle management (PLM). Also presented more detailed definitions of key terms related to the use of the digital twin in PLM, such as digital twin prototype, digital twin instance, digital twin aggregate, and digital twin environment (Grieves et al., 2017). Study by (Tao et al., 2019) introduced a five-dimensional digital twin model, incorporating digital twin data and services, enabling data fusion from both the physical product and its digital counterpart (Liu et al., 2019). Recent studies emphasize the dynamic, real-time, and bi-directional data connection features of digital twin (Fang et al., 2019). The continuous dedication of researchers and practitioners, along with advancements in IoT, Big Data, and cloud computing, has led to the advancement and sophistication of the digital twin model. These factors have created a digitally enabling environment for implementing digital twin technologies, with fewer restrictions than initially outlined. Today, a digital twin is considered a vital pillar of the Industrial Revolution 4.0 in both industrial and academic sectors (Tao et al., 2018), (Pang et al., 2021).

The term "digital twin" has been used to define various models, systems, or technologies, but it has also faced inflated expectations and a lack of standardized definitions. The concept of digital twins has existed for decades, with NASA utilizing it in the 1960s to simulate spacecraft during the Apollo missions. Manufacturing and general industry quickly adopted digital twin technology due to its links with cost reduction and production efficiency. A digital twin consists of three elements: the physical product, its virtual representation, and the bi-directional data connections between them. It involves creating a virtual model to simulate entity behaviors, monitor status, recognize complexities, detect patterns, reflect performance, and predict trends.

Digital twin technology has become crucial in product lifecycle management (PLM), and various terms related to its use in PLM have been defined. Researchers have expanded on the initial three-dimensional digital twin model, introducing a five-dimensional model that incorporates data and services. Recent studies highlight the dynamic, real-time, and bi-directional data connection features of digital twins. The advancement and sophistication of the digital twin model are attributed to the dedication of researchers and practitioners, as well as advancements in IoT, Big Data, and cloud computing. These factors have created a digitally enabling environment for implementing digital twin technologies. Today, a digital twin is considered a vital pillar of the Industrial Revolution 4.0 in both industrial and academic sectors.

2.1.1 Healthcare Advancements through the Virtual Twin

The implementation of Virtual twin technology has led to significant advancements in manufacturing industries, where it has been integrated into every stage of product lifecycle management (PLM). It has been recognized as a crucial element of Industry 4.0 (Tao et al., 2018), (Zhang et al., 2018). The interest in digital twins is evident across various industries and sectors, with particular attention being given to the rapidly developing healthcare sector, especially in response to the COVID-19 pandemic (Mendi et al., 2020), (Gabellini et al., 2020), (Laubenbacher et al., 2021).

In the healthcare context, the five-dimensional model of the digital twin (Liu et al., 2019) holds relevance. However, practical implementation in healthcare is far more complex and challenging compared to other industries. Healthcare involves dealing with human patients rather than traditional "products" and encompasses a high level of variety and complexity. This complexity necessitates the utilization of sophisticated domain-specific knowledge at every stage of the process. Additionally, healthcare presents numerous ethical concerns, regulatory requirements, and challenges related to privacy and security that must be carefully addressed (Bruynseels et al., 2018).

Therefore, the following study will show the following: Virtual twin technology has had significant advancements in manufacturing industries and has been recognized as a crucial element of Industry 4.0. The healthcare sector has also shown interest in digital twins, especially in response to the COVID-19 pandemic. Implementing virtual twin technology in healthcare is more complex and challenging due to the unique nature of dealing with human patients and the ethical, regulatory, privacy, and security concerns involved.

To address the impact of virtual twin technology on patient engagement in healthcare:

There is a growing body of research on the impact of virtual twin technology on patient engagement (Anderson et al., 2022). This study conducted at the University of California, San Francisco, aimed to assess the impact of virtual twin technology on patient engagement in healthcare. Researchers conducted a comparative analysis between patients who utilized virtual twins to track their health conditions and those who did not use the technology. The study found that patients who used virtual twins exhibited higher levels of treatment plan adherence compared to their counterparts. They were more likely to adhere to prescribed medications, follow lifestyle modifications, and participate actively in their treatment plan.

Furthermore, the patients using virtual twin technology demonstrated better clinical outcomes compared to those who did not. The virtual twin technology enabled real-time monitoring of patient's health parameters and provided healthcare providers with valuable insights into their condition, facilitating prompt interventions and adjustments to treatment plans as needed. Moreover, patients who used virtual twins reported higher levels of satisfaction with their care and felt more in control of their health. The interactive nature of virtual twins allowed patients to actively participate in their care and collaborate with healthcare providers in decision-making processes, leading to increased patient empowerment (Rizzo et al., 2021).

The Mayo Clinic study aimed to explore the use of virtual twin technology in the context of cardiac rehabilitation. Researchers assessed the impact of virtual twins on patient engagement and long-term outcomes for individuals undergoing cardiac rehabilitation programs. Also, this study found that patients who used virtual twins to track their heart health were more likely to participate actively in cardiac rehabilitation programs compared to those who did not use the technology. This increased engagement in rehabilitation programs resulted in better long-term outcomes, including improved cardiac function and reduced risk of complications. Additionally, patients using the virtual twin technology reported feeling better about their health and were more likely to recommend the technology to others. The visual representation of their health status and progress through the virtual twin empowered patients to take ownership of their health and motivated them to adhere to their rehabilitation plans.

According to (Liu et. al., 2019), the CloudDTH study proposed a novel cloud-based framework for elderly healthcare services using digital twins. The objective was to facilitate remote monitoring of elderly patients' health conditions, enabling personalized care delivery. Also, this study on virtual twin technology implemented in the CloudDTH framework allowed continuous tracking of vital signs, medication adherence, and other relevant health data of elderly patients. This real-time monitoring provided healthcare providers with a comprehensive view of the patient's health status and allowed for timely interventions when necessary. Lastly, this study demonstrated that virtual twin-based remote monitoring systems significantly improved patient engagement. Elderly patients could actively participate in their care through access to their virtual twin representations, leading to increased awareness and better self-management of their health conditions. According to (Mousavi et al., 2020), the study focused on enhancing patient engagement through virtual twin-based remote monitoring systems. The researchers evaluated the impact of virtual twin technology on patients' involvement in their healthcare journey and their ability to manage their health effectively. This study also demonstrated that continuous tracking of vital signs, medication adherence, and other relevant health data through virtual twin technology significantly improved patient engagement. Patients had access to their virtual twin representations, allowing them to actively participate in their care and make informed decisions regarding their health. Also, this virtual twin-based remote monitoring systems provided healthcare providers with real-time data, enabling them to tailor treatment plans and interventions based on the patient's individual needs. The personalized care delivery facilitated by virtual twin technology led to improved health outcomes and patient satisfaction.

According to (Rieke et al., 2021), the study explored the role of interactive interfaces and visualizations through virtual twin technology in empowering patients to make informed healthcare decisions. Researchers assessed the impact of these interfaces on patients' understanding of their health conditions, treatment plans, and lifestyle modifications. The study also findings revealed that the use of interactive interfaces and visualizations through virtual twin technology significantly enhanced patients' understanding of their health status and treatment plans. Patients could visually interact with their virtual twin representations, which made complex medical information more accessible and easier to comprehend.

This increased comprehension empowered patients to actively participate in their healthcare decisions. Patients felt more confident in making informed choices about their treatment options, lifestyle modifications, and self-management strategies. The study by (Zeadally et al. 2021) addresses a crucial concern associated with virtual twin technology in healthcare: data privacy and security. The researchers emphasized the importance of implementing robust cybersecurity measures and adhering to privacy regulations to safeguard patient information from unauthorized access and breaches. Virtual twin technology involves extensive collection and analysis of patient data, making data protection and ethical considerations critical aspects to address. The study highlighted the need for responsible use of virtual twin technology to build and maintain patient trust in the healthcare system.

In conclusion, these studies collectively provide compelling evidence of the positive impact of virtual twin technology on patient engagement in healthcare. The research consistently demonstrates that virtual twin technology empowers patients, improves treatment plan adherence, enhances clinical outcomes, and promotes patient education and self-management. Moreover, the studies underscore the importance of addressing data privacy and security concerns to ensure the ethical and responsible implementation of virtual twin technology in healthcare settings.

The effects of virtual twin technology on clinical decision-making processes:

Virtual twin technology (VTT) is a rapidly developing field with the potential to revolutionize clinical decision-making processes. VTT creates a digital replica of a patient or clinical process, which can be used to simulate different scenarios and outcomes. This can help clinicians to identify and mitigate risks, optimize care plans, and make more informed decisions. found that VTT can be used to improve the accuracy of cancer diagnoses. A recent study published in the journal “Nature Medicine 2022” This groundbreaking study aimed to assess the impact of virtual twin technology on cancer diagnosis. The researchers created digital replicas (virtual twins) of 100 patients with different types of cancer, representing various stages and characteristics of the disease. These virtual twins were used to train a machine-learning algorithm to identify cancer cells accurately. The results were remarkable, indicating that the algorithm achieved an accuracy rate of 95% in correctly identifying cancer cells. This level of accuracy significantly surpassed traditional diagnostic methods. By harnessing virtual twin technology, clinicians can access comprehensive and real-time data about patients, enabling them to make more informed and precise decisions when diagnosing cancer. The virtual twin technology enhances clinical decision-making by providing healthcare professionals with valuable insights and facilitating personalized and accurate cancer diagnoses. Another study, published in the journal article “Science Translational Medicine 2022 study focused on the application of virtual twin technology to predict the risk of sepsis in patients with pneumonia. Researchers created digital twins of 100 patients with pneumonia, monitoring their physiological data continuously over time. By analyzing this data through virtual twin representations, the researchers aimed to predict the risk of sepsis in these patients. The findings revealed that the virtual twin technology successfully predicted the risk of sepsis with an impressive accuracy rate of 85%. Identifying patients at risk of sepsis early is critical for timely interventions and improved patient outcomes. Virtual twin technology aids clinical decision-making by enabling early recognition of potential complications and facilitating appropriate interventions, ultimately leading to better patient care.

According to (Shrestha et al. 2022) this study show systematic review conducted to explore the potential applications of virtual twin technology in healthcare. Although specific findings were not provided in the given text, systematic reviews typically analyze existing literature on a particular topic to identify trends, gaps, and potential benefits. This review likely investigated various healthcare settings where virtual twin technology has been applied and its implications for clinical decision-making. This scoping review conducted (Quilici et al., 2021) . aimed to explore the role of virtual twins in healthcare. Scoping reviews aim to map key concepts and identify gaps in research literature. While specific findings were not mentioned in the provided text, this review likely provided an overview of the different applications of virtual twin technology in healthcare, including its relevance to clinical decision-making processes. In this systematic review, (Alavi et al., 2022). investigated the patient acceptance of virtual twin technology in healthcare. The review included 17 studies conducted in various healthcare settings, examining patients' perspectives and attitudes towards using virtual twin technology. The findings indicated that patients generally had positive attitudes towards virtual twin technology. They were particularly interested in the potential of virtual twin technology to improve their health outcomes, provide them with more control over their care, and reduce healthcare costs. Understanding patient acceptance and preferences is crucial for designing user-friendly virtual twin systems that effectively engage patients in their healthcare decisions.

In summary, the provided references collectively highlight the transformative potential of virtual twin technology in enhancing clinical decision-making processes. The studies demonstrated that virtual twin technology can significantly improve cancer diagnosis accuracy and predict the risk of sepsis, enabling timely and informed interventions. Furthermore, the systematic and scoping reviews emphasize the diverse applications of virtual twin technology in healthcare and patients' positive attitudes towards its adoption. While these findings are promising, further research is needed to fully understand the breadth of benefits and challenges associated with integrating virtual twins into routine clinical decision-making practices effectively.

The contribution of virtual twin technology to improving healthcare outcomes: Virtual twin technology also has the potential to significantly impact clinical decision-making processes by enabling real-time patient monitoring, predictive analytics, and simulation-based scenario analysis. This comprehensive review conducted by (Sun et al., 2023) explores the progress and potential applications of digital twin technology in healthcare. The study highlights the transformative impact of digital twins on healthcare outcomes. Digital twins create virtual replicas of patients, enabling real-time monitoring of their health parameters and treatment progress. This technology supports predictive analytics, personalized care, and data-driven decision-making, leading to improved patient outcomes.

The review identifies various potential applications of digital twin technology in healthcare, including:

I. Early disease detection: Digital twins can continuously monitor patients' health data, allowing for early detection of abnormalities and timely intervention.

II. Personalized treatment plans: Digital twins enable a more precise understanding of each patient's health status, facilitating personalized treatment plans tailored to individual needs.

III. Treatment optimization: Through real-time monitoring and data analysis, digital twins help optimize treatment plans and adapt them as needed, resulting in more effective care.

IV. Predictive analytics: Digital twins use historical data to predict future health trends and potential complications, allowing clinicians to proactively manage patients' health.

V. Medical education and training: Digital twins serve as valuable educational tools for medical professionals, providing realistic simulations and training scenarios. While not directly focused on healthcare, (Augustine, 2020) work in the field of product lifecycle management highlights the principles and potential benefits of digital twins. In healthcare, these principles can be translated to patient care and operational management.Digital twin technology allows for a better understanding of complex systems, optimization of processes, and effective decision-making, all of which can lead to improved healthcare outcomes. Although not specifically in healthcare, (Kuo et al., 2021) study examines the challenges and opportunities of digital twins in smart industrial systems. The challenges and lessons learned from applying digital twin principles in other domains can be adapted and applied to healthcare settings. Digital twins can help streamline healthcare processes, enhance medical device development, and optimize smart medical systems, leading to better patient care and outcomes. This study by (Pesapane et al., 2022) review focuses on the application of digital twins specifically in radiology. By creating accurate and dynamic patient models, digital twins in radiology contribute to improved diagnostic accuracy and more precise treatment planning. The use of digital twins allows radiologists to analyze patient-specific data in real-time, leading to enhanced patient care outcomes and treatment decisions. There is a growing body of research that suggests that VTT can improve healthcare outcomes. This ground-breaking study showcased the impact of virtual twin technology on cancer diagnosis. By creating digital replicas of patients with cancer and training a machine-learning algorithm, the study achieved an impressive 95% accuracy in identifying cancer cells. Virtual twin technology enables real-time monitoring and analysis of patient data, leading to more accurate and timely diagnoses, personalized treatment plans, and ultimately, improved patient outcomes. The use of virtual twins allowed continuous monitoring of patients' physiological data, enabling the prediction of sepsis risk with an accuracy rate of 85%. Early identification of patients at risk of sepsis can lead to timely interventions, resulting in improved patient care and outcomes. In conclusion, the referenced studies collectively demonstrate the significant contribution of virtual twin technology to improving healthcare outcomes. The technology enables real-time monitoring, predictive analytics, personalized treatment plans, and early intervention strategies, all of which lead to enhanced patient care and decision-making processes. Additionally, principles learned from digital twins in other domains, such as product lifecycle management and smart industrial systems, can be applied to healthcare settings to optimize operational efficiencies and overall patient care.

2.2 Theory of Reasoned Action

The Theory of Reasoned Action (TRA) provides a valuable framework for understanding and predicting individuals' behavior based on their beliefs, attitudes, and intentions. In the context of healthcare and the adoption of virtual twin technology, the TRA offers insights into how individuals form intentions to use or engage with such innovative tools. Two key components of the theory, attitudes and subjective norms, play a crucial role in shaping behavioral intentions.

According to the TRA, attitudes refer to individuals' positive or negative evaluations of performing a particular behavior. In the healthcare domain, attitudes toward the use of virtual twin technology may be influenced by perceptions of its effectiveness in improving patient outcomes, enhancing clinical decision-making, and promoting overall healthcare efficiency (Ajzen & Fishbein, 1980). Positive attitudes are likely to lead to a stronger intention to use virtual twin technology in healthcare settings.

Subjective norms, another core element of the TRA, encompass perceived social pressures or expectations regarding the behavior in question. In healthcare, this could involve the influence of colleagues, healthcare providers, or institutional norms on an individual's decision to embrace virtual twin technology. Positive subjective norms, indicating social approval or support for using virtual twin tools, are expected to contribute positively to behavioral intentions.

Several studies have applied the TRA to understand technology adoption in healthcare contexts. To examine healthcare professionals' intentions to adopt virtual twin technology in their clinical practices. The findings indicated that positive attitudes towards the technology's benefits and favorable subjective norms significantly influenced the participants' intentions to use virtual twin tools.

In conclusion, the Theory of Reasoned Action provides a robust theoretical foundation for investigating the factors influencing the adoption of virtual twin technology in healthcare. By considering attitudes and subjective norms, researchers and practitioners can gain valuable insights into the determinants of behavioral intentions, facilitating the successful integration of innovative technologies in healthcare settings.

Reference: (Ajzen et al., 1980). Understanding Attitudes and Predicting Social Behavior. Englewood Cliffs, NJ: Prentice-Hall

2.3 Human Society Theory

The concept of a virtual twin, or digital twin, has been gaining traction in recent years, particularly in the healthcare industry. A virtual twin is a digital representation of a physical object or system, which can be used to simulate and predict its behavior. In the context of healthcare, virtual twins can be used to model the human body and simulate various diseases and treatments. This information can then be used to personalize care and improve patient outcomes.

The integration of virtual twins in healthcare reflects a convergence of technology and human society, prompting an exploration of sociological theories to understand its impact. One pertinent framework is the Social Construction of Technology (SCOT) theory, emphasizing the mutual shaping of technology and society (Pinch et al., 1984). In the context of virtual twins in healthcare, SCOT underscores the collaborative process through which societal factors, values, and needs influence the development and adoption of this technology. The referenced articles provide insights into the socio-ethical considerations and benefits associated with digital twins in healthcare, aligning with SCOT's emphasis on the social context of technological innovation.

The concept of personalized healthcare, facilitated by virtual twins, aligns with the principles of Technological Determinism. This theory posits that technology influences and shapes societal structures and values (Winner et al., 1980). In healthcare, the personalized models created by virtual twins represent a technological shift influencing how individuals perceive and engage with their health, thereby supporting the tenets of Technological Determinism.

Moreover, the challenges identified, such as data privacy concerns and the complexity of modeling the human body, resonate with broader sociological discussions on the impact of technology on society. Issues of data privacy align with debates on information security and the implications of extensive data collection in the digital age.

In conclusion, the adoption of virtual twins in healthcare reflects a complex interplay between technology and society. Sociological theories such as SCOT and Technological Determinism offer valuable perspectives to analyze how virtual twins are both influenced by and, in turn, shape human society in the realm of healthcare. Ongoing research and discourse on the socio-ethical implications underscore the importance of a nuanced understanding of the societal dimensions of this technological advancement.

2.4 Summary

The term "Virtual twin" encompasses various models, systems, and technologies, and its conceptualization has evolved over decades. Originating in the 1960s with NASA's use in spacecraft simulation, the term was formally defined in 2012 as an integrated, multi-physics, multi-scale simulation. Initially prevalent in manufacturing, the digital twin concept expanded into healthcare with implications for Industry 4.0. A digital twin comprises a physical product, its virtual representation, and bi-directional data connections, aiding real-time monitoring and predictive simulations.

In healthcare, the five-dimensional digital twin model proves relevant but faces unique challenges due to human-centric complexities. Privacy, security, ethical concerns, and regulatory requirements demand meticulous attention. The preliminary literature review establishes the historical evolution of digital twins and their applications, especially in manufacturing and healthcare.

The subsequent section delves into the impact of virtual twin technology on healthcare, focusing on patient engagement, clinical decision-making, and healthcare outcomes. Studies from diverse sources provide evidence of positive outcomes. Patient engagement benefits from real-time monitoring, empowering patients and improving adherence. Virtual twins enhance clinical decision-making through accurate diagnoses and predictive analytics, contributing to early intervention. Additionally, the technology positively influences healthcare outcomes by enabling personalized treatment plans, optimizing care, and improving diagnostic accuracy.

The theory of reasoned action (TRA) is introduced as a framework to understand behavioral intentions towards virtual twin adoption. Attitudes and subjective norms play pivotal roles, influencing individuals' willingness to engage with this innovative technology. Existing studies on healthcare professionals' intentions align with TRA principles, emphasizing the importance of positive attitudes and supportive social norms.

The discussion extends to sociological perspectives, particularly the Social Construction of Technology (SCOT) theory and Technological Determinism. SCOT highlights the reciprocal relationship between virtual twin technology and society, emphasizing socio-ethical considerations. Technological Determinism suggests that technology shapes societal values, evident in the shift towards personalized healthcare facilitated by virtual twins.

In summary, the integration of virtual twins in healthcare represents a dynamic interplay between technology and society. The evolution from manufacturing to healthcare, coupled with positive outcomes in patient engagement, clinical decision-making, and healthcare overall, underscores the transformative potential. Theories like TRA, SCOT, and Technological Determinism provide lenses to understand adoption patterns, societal influences, and ethical considerations in this technological advancement. Ongoing research and interdisciplinary collaboration remain crucial in navigating the evolving landscape of virtual twin technology in healthcare.

CHAPTER III:

METHODOLOGY

3.1 Overview of the Research Problem

The research problem at the core of this study revolves around the transformative potential of virtual twin technology within the healthcare sector. Virtual twin technology involves creating a digital replica or simulation of physical entities, in this case, within the healthcare domain. The research acknowledges the escalating adoption of this technology and seeks to thoroughly explore its ramifications across three critical dimensions:

3.1.1 Patient Engagement:

The study aims to dissect how the integration of virtual twin technology influences and shapes patient engagement within healthcare practices. Patient engagement refers to the active involvement of patients in their own healthcare journey, including aspects like adherence to treatment plans, understanding of medical conditions, and participation in decision-making.

3.1.2 Clinical Decision-Making Processes:

A significant focus is placed on understanding how virtual twin technology impacts the decision-making processes of healthcare professionals. This involves investigating whether the technology contributes to more informed, accurate, and efficient clinical decisions. The complexity of clinical decision-making, particularly in the context of emerging technologies, is a key aspect of the research problem.

3.1.3 Healthcare Outcomes:

The study recognizes that the ultimate goal of any healthcare intervention is to enhance overall outcomes. Here, the research problem probes into how the adoption of virtual twin technology contributes to the broader landscape of healthcare outcomes. This includes assessing its potential to improve patient health indicators, treatment success rates, and patient-reported outcomes.

3.2 Operationalization of Theoretical Constructs

Theoretical Framework: The study is anchored in a theoretical framework that posits the potential benefits of virtual twin technology within the healthcare sector. The theoretical framework serves as the intellectual foundation, guiding the research design and shaping the investigation into the impact of virtual twin technology on patient engagement, clinical decision-making processes, and healthcare outcomes.

Delphi Method: The Delphi method is chosen as a research method for its suitability in gathering expert opinions and insights in a structured and iterative manner. The operationalization of the Delphi method involves several key steps:

3.2.1 Identification of Experts:

The researchers will identify a panel of experts relevant to the field of virtual twin technology in healthcare. These experts may include healthcare professionals, researchers, technology developers, and other stakeholders with substantial experience and knowledge in the domain.

3.2.2 Structured Questionnaire Development:

A structured questionnaire will be designed with clear and focused questions related to virtual twin technology. These questions may cover diverse aspects such as potential applications, challenges, and perceived impacts. The structured nature of the questionnaire ensures consistency and reliability in data collection.

3.2.3 Iterative Rounds of Feedback:

The Delphi method involves multiple rounds of feedback. In each round, the experts provide responses to the questionnaire. The responses are then compiled and anonymized before being fed back to the experts. The experts have the opportunity to revise their responses in light of the collective input from the group.

3.2.4 Consensus Building:

The process continues until a level of consensus is reached among the experts. The Delphi method aims to distill expert opinions into a coherent set of insights, highlighting areas of agreement and, in some cases, exposing divergent perspectives.

3.2.5 Quantification of Qualitative Data:

While the Delphi method is inherently qualitative, the data obtained from experts' responses can be quantified to some extent. This may involve assigning numerical values to qualitative responses for statistical analysis, providing a structured representation of the qualitative insights.

3.3 Research Purpose and Questions

The purpose of this research is to provide a comprehensive understanding of how virtual twin technology impacts patient engagement, clinical decision-making, and healthcare outcomes. By addressing these facets, the study seeks to bridge the gap between technological advancements and effective healthcare delivery, offering insights that can guide the ethical and efficient integration of virtual twin models in diverse healthcare settings can be addressed with 3 points.

3.3.1 Research Question 1: How does virtual twin technology impact patient engagement in healthcare?

Understanding the influence of virtual twin technology on patient engagement is pivotal in reshaping healthcare dynamics. (Han et al., 2020) emphasize the potential of virtual twin models to empower patients through visualization and simulation of their health conditions. This engagement goes beyond traditional patient-doctor interactions, offering patients a more active role in their healthcare journey. As patients visualize their conditions and actively participate in decision-making, the study aims to illuminate the nuanced ways in which virtual twin technology fosters informed patient engagement.

3.3.2 Research Question 2: What are the effects of virtual twin technology on clinical decision-making processes?

The intricate landscape of clinical decision-making stands to be significantly influenced by the integration of virtual twin technology. (Turner et al.,2019) highlight the capacity of virtual twin models to assimilate patient-specific data and predictive analytics, providing healthcare professionals with a refined understanding of individual cases. The study ventures into the realm of decision refinement, workflow optimization, and enhanced clinical efficiency. By unraveling these effects, the research seeks to contribute a comprehensive view of how virtual twin technology transforms the decision-making processes of healthcare professionals.

3.3.3 Research Question 3: Can virtual twin technology contribute to improving healthcare outcomes?

According to (Brown et al., 2020) underline the potential of virtual twin technology to translate into tangible improvements in healthcare outcomes. Through leveraging real-time patient data, simulation capabilities, and personalized insights, virtual twin models have the capacity to optimize treatment strategies and detect health issues in their early stages. The study aims to dissect these contributions, providing a nuanced understanding of how virtual twin technology can elevate healthcare quality. By exploring treatment optimization, early issue detection, and personalized care delivery, the research seeks to offer valuable insights into the transformative impact of virtual twin technology on overall healthcare outcomes.

3.4 Research Design

The research design serves as the blueprint for the study, outlining the overall plan and strategy for investigating the impact of virtual twin technology in the healthcare sector. It is carefully crafted to address the multifaceted nature of the research problem and achieve a comprehensive understanding of the phenomenon under investigation.

Incorporation of Quantitative and Qualitative Approaches: The research design is distinctive in its integration of both quantitative and qualitative approaches. This dual-method strategy is chosen to harness the strengths of each approach, providing a holistic and nuanced perspective on the impact of virtual twin technology. The combination of methods allows for a more comprehensive exploration of the research questions and enhances the robustness of the study.

3.5 Population and Sample

The sample selection criteria in the context of virtual twin technology in healthcare will be as follows:

3.5.1 Healthcare Professionals

I. Specialities: Healthcare professionals from different specialities, such as doctors, nurses, radiologists, or surgeons, will be selected to capture a diverse range of perspectives.

II. Experience: Both experienced professionals who have used virtual twin technology and those who have not will be included to compare their insights and experiences.

III. Settings: Healthcare professionals working in various healthcare settings, such as hospitals, clinics, or research institutions, will be considered to capture different implementation contexts.

3.5.2 Patients

I. Condition: Patients with different medical conditions will be chosen to explore the potential application of virtual twin technology across various healthcare domains.

II. Treatment Experience: Both patients who have received treatment or care using virtual twin technology and those who have not will be included to understand their experiences and perspectives.

III. Demographics: Demographic factors such as age, gender, and socio-economic status will be considered to ensure diversity within the sample.

3.5.3 Healthcare Organizations

I. Size: Healthcare organizations of different sizes, such as large hospitals, small clinics, or research institutions, will be selected to examine the implementation of virtual twin technology in various contexts.

II. Technological Sophistication: Organizations at different stages of technology adoption and with varying levels of experience with virtual twin technology will be chosen.

III. Geographic Location: Organizations from different geographical locations will be included to account for potential regional variations in the utilization of virtual twin technology.

3.5.4 Experts and Key Stakeholders

I. Researchers and Innovators: Experts who have conducted research or made significant contributions to the field of virtual twin technology in healthcare will be included.

II. Technology Developers: Professionals or representatives from companies or organizations that develop and provide virtual twin solutions specifically for healthcare applications will be involved.

3.6 Participant Selection

Exclusion and inclusion criteria are important for selecting participants who align with the research objectives. For a study on the impact of virtual twin technology in healthcare, the following exclusion and inclusion criteria can be used:

Inclusion Criteria:

I. Age: Participants must be adults aged 18 and above.

II. Healthcare Setting: Participants must work in a clinical healthcare setting.

III. Familiarity with Virtual Twin Technology: Participants should have some level of familiarity with virtual twin technology in healthcare.

IV. Experience: Participants must have a minimum of 10 years of experience in their respective healthcare field like focus on specific medical specialties, such as orthopedics, cardiology, neurology, dermatology, general surgery, internal medicine, oncology, and obstetrics/gynecology

3.6.1 Exclusion Criteria:

I. Age: Participants under the age of 18 are excluded.

II. Non-Healthcare Setting: Participants who do not work in a clinical healthcare setting are excluded.

III. Lack of Familiarity: Participants without knowledge or experience with virtual twin technology in healthcare are excluded.

IV. Insufficient Experience: Participants with less than 10 years of experience in their respective healthcare field are excluded.

3.7 Instrumentation

3.7.1. Surveys or Questionnaires:

I. Purpose: Structured surveys or questionnaires are designed to gather quantitative data on virtual twin technology usage, perceptions, and experiences.

II. Participants: Patients, healthcare providers, and relevant stakeholders.

III. Content:

- **a.** Frequency of Usage: Participants are asked about how often they use virtual twin technology in their healthcare practices.
- **b.** Effectiveness for Diagnosis: For healthcare providers, questions assess the effectiveness of virtual twin technology in aiding the diagnostic process.
- **c.** Contribution to Treatment Planning: Participants are queried on how they utilize virtual twin technology for treatment planning and its perceived contribution.
- **d.** Integration into Patient Monitoring: For healthcare providers, questions explore the integration of virtual twin technology into patient monitoring processes and its impact.
- **e.** Patient Education and Engagement: Questions focus on how virtual twin technology is incorporated into patient education and its effectiveness in improving patient understanding and involvement in healthcare.

3.7.2. Interviews:

I. Purpose: In-depth interviews are conducted to gather qualitative insights into the impact of virtual twin technology.

II. Participants: Healthcare professionals, patients, and experts in the field.

III. Content:

  a. Experiences and Challenges: Participants are encouraged to share their personal experiences, challenges faced, and potential benefits observed in the use of virtual twin technology.

  b. Perceptions of Impact: Interviews explore how participants perceive the impact of virtual twin technology on patient engagement, clinical decision-making, and healthcare outcomes.

3.7.3 Advantages of Instrumentation Approach:

I. Triangulation of Data: The use of multiple instruments enables triangulation, cross-validating findings from different sources and methods.

II. Comprehensive Insights: Surveys provide quantitative metrics, while interviews and observational studies offer qualitative depth, ensuring a comprehensive understanding of the impact of virtual twin technology.

III. Rich Qualitative Data: Interviews and observational studies capture rich, context-specific qualitative data, providing valuable insights into the practical application and experiences of virtual twin technology.

3.7.4 Considerations:

I. Ethical Considerations: Informed consent, confidentiality, and ethical treatment of participant data are paramount considerations in the use of these instruments.

II. Feasibility: Practical constraints, such as access to participants and data, are considered to ensure the feasibility of employing these instruments.

In essence, the multifaceted instrumentation approach is designed to capture a holistic view of the impact of virtual twin technology in healthcare, combining quantitative data from surveys with qualitative insights gathered through interviews, observations, and analysis of documentary sources. This comprehensive strategy enhances the validity and reliability of the study's findings.

3.8 Data Collection Procedures

The research employs a combination of structured surveys or questionnaires, in-depth interviews, observational studies, and the analysis of documentary and archival sources. This comprehensive data collection strategy ensures the gathering of both quantitative and qualitative data relevant to the research questions. It allows for a thorough exploration of virtual twin technology's role in healthcare.

3.8.1. Surveys or Questionnaires:

I. Distribution: Structured surveys or questionnaires are distributed to participants, including patients, healthcare providers, and relevant stakeholders.

II. Online: Depending on the feasibility and preferences of participants, surveys may be administered online or as paper-based forms.

III. Quantitative Data Collection: Participants respond to questions that capture quantitative data on the frequency of virtual twin technology usage, its effectiveness for diagnosis, contribution to treatment planning, integration into patient monitoring, and its impact on patient education and engagement.

3.8.2. Interviews:

I. Selection of Participants: Participants for in-depth interviews, including healthcare professionals, patients, and experts, are selected based on their relevance to the research objectives.

II. Qualitative Data Collection: Through open-ended questions, participants provide qualitative insights into their experiences, challenges, and perceptions related to virtual twin technology.

3.9 Data Analysis

The collected data will be analyzed using appropriate statistical techniques for quantitative data, such as regression analysis, to identify relationships between variables. Qualitative data from interviews and observations will be analyzed using thematic analysis to uncover recurring patterns, themes, and insights.

This sample is representative enough to provide meaningful insights. Consider factors such as feasibility, access to participants, and specific research objectives when determining the sample size

Table 2.1
Interview Questions

Sr No	**Interview Question**	**Finding**	**Scale**
1	How often do you use virtual twin technology in your healthcare practice?	Frequency of Virtual Twin Technology Usage	Strongly Disagree = 1 | "Disagree" = 2 | "Neutral" = 3 | "Agree" = 4 | "Strongly Agree" = 5
2	Have you used virtual twin technology for diagnosis purposes? how would you rate its effectiveness in aiding the diagnostic process?	Virtual Twin Technology Usage for Diagnosis	Not Effective = 0 | "Highly Effective"=1
3	In what ways have you utilized virtual twin technology for treatment planning? , how would you rate the contribution of virtual twin technology in developing comprehensive treatment plans?	Virtual Twin Technology Usage for Treatment Planning	No Contribution= 0 | "Significant Contribution"=1

4	Have you integrated virtual twin technology into patient monitoring processes? , how would you rate the improvement in patient monitoring due to virtual twin technology?	Virtual Twin Technology Usage for Monitoring	"No Improvement" - 0 | "Significant Improvement"=1
5	How do you incorporate virtual twin technology in patient education and engagement? how effective do you find virtual twin technology in improving patient understanding and involvement in their healthcare?	Virtual Twin Technology Usage for Patient Education	"Not Effective"=0 | Highly Effective
6	How do you perceive the level of patient activation in managing their healthcare? how would you rate the impact of virtual twin technology on patient activation?	Patient Activation	scale of 1 to 100 |"No Impact" = 1 -49 | "Impact" = 50-69 | "Strong Impact" = 70-100|
7	How satisfied are your patients with their healthcare experiences, including interactions with healthcare professionals and treatment outcomes? how much do you believe virtual twin technology has contributed to patient satisfaction?	Patient Satisfaction	Scale | "Not Satisfaction"=0 | "Highly Satisfaction"=1
8	How involved do patients feel in the decision-making process regarding their treatment options? how would you rate the influence of virtual twin technology on patient involvement in decision-making?	Patient Involvement in Decision-Making	scale of 1 to 50 "No Influence"=1-20 | "Influence"= 20-40| "Significant Influence"=40-50
9	How frequently are you involved in making clinical decisions in your current role?	Role in Clinical Decision Activation	Scale 1to 10 "Strongly Disagree" = 1 -3 | "Disagree" = 4-6 | "Agree" = 7-8| "Strongly Agree" = 9-10
10	How satisfied are you with your current level of involvement in clinical decision-making? Please rate on a	Role in Clinical Decision Satisfaction	Scale 1 to 10 "Strongly Disagree" = 1 -3 | "Disagree" = 4-6 | "Agree" = 7-8| "Strongly Agree" = 9-10

11	How involved do you feel in the clinical decision-making processes?	Role in Clinical Decision Involvement	Scale 1 to 10 "Strongly Disagree" = 1 -3 | "Disagree" = 4-6 | "Agree" = 7-8| "Strongly Agree" = 9-10
12	How positively do you perceive the impact of virtual twin technology on clinical decision-making processes?	Effects on Decision-making	Scale 1 to 10 "Strongly Disagree" = 1 -3 | "Disagree" = 4-6 | "Agree" = 7-8| "Strongly Agree" = 9-10
13	How strongly do you believe that virtual twin technology contributes to overall improvements in healthcare outcomes?	Healthcare Outcome	Scale 1 to 100 "Strongly Disagree" = 1 -29 | "Disagree" = 30-49 | "Agree" = 50-79| "Strongly Agree" = 80-100

RQ1. Virtual twin technology impacts patient engagement in healthcare

To examine the impact of virtual twin technology on patient engagement in healthcare, a mixed-methods approach can be employed, drawing from a growing body of research. (Anderson et al., 2022) conducted a study at the University of California, San Francisco, which found that patients who used a virtual twin to track their health demonstrated higher adherence to treatment plans and achieved better clinical outcomes compared to those who did not use the virtual twin. Thestudy also revealed that virtual twin users reported higher satisfaction with their care and a greater sense of control over their health. Similarly, (Rizzo et al., 2021), study conducted at the Mayo Clinic, observed that patients utilizing a virtual twin for monitoring heart health were more likely to engage in cardiac rehabilitation programs and experienced improved long-term outcomes in comparison to non-users.

By adopting a mixed-methods approach, researchers can gather qualitative and quantitative data to gain a comprehensive understanding of the impact of virtual twin technology on patient engagement in healthcare by:

I. **Qualitative Phase:** Interviews can be conducted with healthcare professionals to gather their insights and experiences related to virtual twin technology and patient engagement. The interview questions provided in the previous response can be used as a starting point.

II. **Quantitative Phase:** A survey can be designed to quantitatively assess patient engagement and its relationship with virtual twin technology. The survey can include validated scales or items that measure different aspects of patient engagement, such as patient activation, patient satisfaction, or patient involvement in decision-making. Additionally, the survey can include questions related to the frequency and effectiveness of virtual twin technology

Variables for the Regression Model:

Independent Variable: Virtual twin technology usage

I. Frequency of usage: A continuous variable representing how often virtual twin technology is used by healthcare professionals in patient care.

II. Specific applications: A categorical variable indicating the specific applications of virtual twin technology, such as diagnosis, treatment planning, monitoring, or patient education. Each application can be represented as a binary variable (0 or 1), where 1 represents the presence of that application and 0 represents its absence.

III. Dependent Variables: Patient engagement measures

    a. Patient activation: A continuous variable measuring the degree to which patients actively manage their healthcare, make informed decisions and participate in their treatment.

b. Patient satisfaction: A continuous variable capturing patients' overall satisfaction with their healthcare experience, including their interactions with healthcare professionals and the effectiveness of their treatments.

c. Patient involvement in decision-making: A categorical variable indicating the extent to which patients are included in the decision-making process regarding their treatment options. It can be represented as a Likert scale or a binary variable (0 or 1), where 1 represents high involvement and 0 represents low involvement.

Regression equations and variable definitions on the impact of virtual twin technology on patient engagement in healthcare:

I. Regression Equation for Patient Activation: y_activation = b0 + b1(x_frequency) + b2(x_applications)

a. Variable Definitions:

i. y_activation: Patient activation score, representing the degree of patients' active role in managing their healthcare, making informed decisions, and participating in their treatment.

ii. x_frequency: Frequency of virtual twin technology usage, a continuous variable indicating how often virtual twin technology is used in patient care.

iii. x_applications: Specific applications of virtual twin technology, represented as binary variables (0 or 1) for each application. For example, x_applications could include x_diagnosis, x_treatment_planning, x_monitoring, x_patient_education, etc., where each variable indicates the presence (1) or absence (0) of the corresponding application.

iv. Regression Equation for Patient Satisfaction: y_satisfaction = b0 + b1(x_frequency) + b2(x_applications)

b. Variable Definitions:

i. y_satisfaction: Patient satisfaction score, reflecting patients' overall satisfaction with their healthcare experience, including interactions with healthcare professionals and treatment effectiveness.

ii. x_frequency: Frequency of virtual twin technology usage, a continuous variable indicating how often virtual twin technology is used in patient care.

iii. x_applications: Specific applications of virtual twin technology, represented as binary variables (0 or 1) for each application.

II. Regression Equation for Patient Involvement in Decision-Making: y_involvement = b0 + b1(x_frequency) + b2(x_applications)

a. Variable Definitions:

i. y_involvement: Patient involvement in decision-making, represented as a Likert scale or a binary variable (0 or 1), indicating the extent of patient participation in treatment decisions.

ii. x_frequency: Frequency of virtual twin technology usage, a continuous variable indicating how often virtual twin technology is used in patient care.

iii. x_applications: Specific applications of virtual twin technology, represented as binary variables (0 or 1) for each application.

In each regression equation, b0 represents the intercept term, and b1, b2, etc., represent the coefficients associated with each independent variable.

RQ1. The results of this Patient Activation, Patient Satisfaction: Patient Involvement in Decision-Making can impact patient engagement in Virtual twin

RQ2. Effects of virtual twin technology on clinical decision-making processes

The studies on virtual twin technology have shown potential to enhance clinical decision-making processes by providing healthcare professionals with comprehensive and real-time patient data. Studies conducted in various healthcare settings, including hospitals, clinics, and homes, involving 1,053 patients, have yielded positive findings regarding the impact of virtual twin technology on clinical decision-making (Alavi et al., 2022). Patients expressed interest in the potential of virtual twin technology to improve their health outcomes, increase their control over their care, and reduce healthcare costs. The study also suggests that virtual twin technology enables healthcare professionals to analyze the digital representation of the virtual twin, which provides valuable insights into patients' conditions, progress, and treatment needs. This information supports more accurate diagnoses, personalized treatment plans, and improved patient outcomes. By leveraging virtual twin technology, clinicians can access up-to-date and comprehensive data, facilitating informed decision-making processes.

I. **Qualitative Phase:** Interviews with healthcare professionals on how virtual twin technology supports clinical decision-making.

II. **Quantitative Phase:** A survey can be designed to quantify the effects of virtual twin technology on clinical decision-making. The survey can include items that assess the perceived impact of virtual twin technology on decision-making processes, such as accuracy, efficiency, or confidence in decisions.

Variables for the Regression Model:

I. **Independent Variable: Virtual twin technology usage**

   a. Frequency of usage: A continuous variable representing how often virtual twin technology is used in clinical decision-making processes. It can be measured as the number of times virtual twin technology is utilized within a specific time frame (e.g., per week, per month).

   b. Specific applications: A categorical variable indicating the specific applications of virtual twin technology in clinical decision-making, such as diagnosis, treatment planning, prognostication, or risk assessment. Each application can be represented as a binary variable (0 or 1), where 1 represents the presence of that application and 0 represents its absence.

II. **Dependent Variable: Perceived impact on decision-making**

   a. Accuracy: A continuous variable measuring the perceived improvement in the accuracy of clinical decision-making due to the use of virtual twin technology. This can be assessed using Likert-type scale questions or a continuous rating scale.

b. Efficiency: A continuous variable capturing the perceived efficiency enhancement in clinical decision-making as a result of utilizing virtual twin technology. It can be measured using rating scales or Likert-type questions.

c. Confidence: A continuous variable reflecting the level of confidence healthcare professionals have in their clinical decisions when utilizing virtual twin technology. This can be assessed using Likert-type scale questions or a continuous rating scale.

y_decision-making = b0 + b1(x_role_clinical_decision_activation) + b2(x_role_clinical_decision_satisfaction) + b3(x_role_clinical_decision_involvement)

Where:

a. y_decision-making represents the dependent variable, which measures the effects of virtual twin technology on clinical decision-making processes.

b. x_role_clinical_decision_activation is the independent variable representing the activation level of the role of healthcare professionals in supporting clinical decision-making processes using virtual twin technology.

c. x_role_clinical_decision_satisfaction is the independent variable representing the satisfaction level of healthcare professionals with their role in supporting clinical decision-making processes using virtual twin technology.

d. x_role_clinical_decision_involvement is the independent variable representing the involvement level of healthcare professionals in supporting clinical decision-making processes using virtual twin technology.

e. The regression coefficients b0, b1, b2, and b3 represent the impact of each independent variable on the dependent variable

RQ2. The result of the equation for perceived impact on Decision-making will show the Effects of virtual twin technology on clinical decision-making processes.

RQ3. Virtual twin technology contributes to improving healthcare outcomes

Virtual twin technology has the potential to make a significant contribution to improving healthcare outcomes by facilitating real-time patient monitoring, predictive analytics, and simulation-based scenario analysis. According to (Sun et al., 2023) conducted a review of prominent research on digital twin (DT) technology in medicine to assess its progress, potential applications, future opportunities, and remaining challenges in digital healthcare. Their study highlights the potential benefits of virtual twin technology in healthcare settings.

In addition to (Sun et al., 2023), other influential work, such as that of (Augustine, 2020) and (Kuo et al., 2021), emphasizes the advantages of implementing digital twins in healthcare. Digital twin technology involves creating a virtual representation of a physical system, which can be utilized to monitor, analyze, and optimize the system's performance. By simulating different conditions, digital twins can predict the behavior of the system and aid in preventing failures while enhancing overall performance.The use of virtual twin technology in healthcare enables real-time monitoring of patient data, allowing healthcare professionals to access up-to-date information about patients' conditions and respond promptly to any changes or abnormalities. Predictive analytics based on virtual twin models can assist in identifying potential health risks, predicting disease progression, and optimizing treatment strategies by examine this research question, a combination of qualitative and quantitative methods can be employed.

- **I.** Qualitative Phase: Interviews with healthcare professionals can gather insights into how virtual twin technology contributes to healthcare outcomes. The interview questions provided earlier can be tailored to explore the potential benefits and specific indicators influenced by virtual twin technology.
- **II.** Quantitative Phase: Quantitative data on healthcare outcomes can be collected from patient records or databases. The data can include measures such as patient health indicators, treatment success rates, or patient-reported outcomes.

Variables for the Regression Model:

- **I.** Independent Variable: Virtual twin technology usage
    - **a.** Frequency of usage: A continuous variable representing how often virtual twin technology is used in healthcare processes. It can be measured as the number of times virtual twin technology is utilized within a specific time frame (e.g., per week, per month).
    - **b.** Specific applications: A categorical variable indicating the specific applications of virtual twin technology in healthcare, such as diagnosis, treatment planning, monitoring, or predictive modelling. Each application can be represented as a binary variable (0 or 1), where 1 represents the presence of that application and 0 represents its absence.

II. Dependent Variable: Healthcare outcomes

a. Patient health indicators: Continuous variables representing specific health measures or indicators of patients, such as blood pressure, blood glucose levels, pain scores, or disease severity. These indicators reflect the health status of patients and can be obtained from patient records or assessments.

b. Treatment success rates: A continuous variable representing the rate or percentage of successful treatment outcomes achieved using virtual twin technology. This can be calculated based on predefined criteria or clinical guidelines.

c. Patient-reported outcomes: Continuous variables capturing patient-reported measures of health-related quality of life, satisfaction with treatment, symptom improvement, or functional status. These measures can be obtained through validated questionnaires or surveys administered to patients.

d. Healthcare Outcomes = b0 + b1(Frequency) + b2(Diagnosis) + b3(Treatment Planning) + b4(Monitoring) + b5(Patient Education)

III. Variable Definitions:

a. •Healthcare Outcomes: The dependent variable representing the specific healthcare outcome measures, such as patient health indicators, treatment success rates, and patient-reported outcomes.

b. •Frequency: A continuous independent variable indicating how often virtual twin technology is used in healthcare processes.

c. •Diagnosis, Treatment Planning, Monitoring, Patient Education: Categorical independent variables indicating the presence (1) or absence (0) of specific virtual twin technology applications in healthcare. Each of these variables represents a specific application of virtual twin technology.

In the regression equation, b0 represents the intercept term, and b1, b2, b3, b4, and b5 represent the coefficients associated with each independent variable. These coefficients indicate the magnitude and direction of their impact on the dependent variable (Healthcare Outcomes).

To conduct a regression analysis and estimate the coefficients (b0, b1, b2, b3, b4, b5), you would need a dataset with corresponding values for Frequency, Diagnosis, Treatment Planning, Monitoring, Patient Education, and Healthcare Outcomes.

RQ3. The result of the Equation for virtual twin healthcare outcomes contributes to healthcare.

3.10 Research Design Limitations

I. While the research design is comprehensive, it is essential to acknowledge potential limitations, such as the generalizability of findings and the influence of contextual factors.

II. The study's reliance on self-reporting in surveys and interviews may introduce response bias, emphasizing the importance of considering participants' perspectives critically.

3.11 Conclusion

The research design, encompassing an exploration of virtual twin technology's impact on patient engagement, clinical decision-making processes, and healthcare outcomes, reflects a holistic and rigorous approach. As the study delves into the intricacies of incorporating virtual twin technology into healthcare, it draws upon a combination of research methods to ensure a comprehensive analysis.

Key Highlights:

I. Methodological Versatility: The utilization of both quantitative and qualitative research methods, including the Delphi method, regression analysis, surveys, interviews, observational studies, and archival data analysis, signifies a methodologically versatile and robust design.

II. Diverse Participant Selection: The criteria for sample selection, encompassing healthcare professionals, patients, healthcare organizations, and experts, are thoughtfully designed to capture diverse perspectives and experiences. This diversity is crucial for obtaining a nuanced understanding of virtual twin technology's implementation across various contexts.

III. Thorough Data Collection: The data collection procedures, ranging from structured surveys to in-depth interviews and direct observational studies, are meticulously designed to ensure the gathering of both quantitative and qualitative data. This multifaceted approach is instrumental in exploring the practical implications of virtual twin technology in healthcare.

IV. Integration and Triangulation: The integration of quantitative and qualitative data, coupled with triangulation across different data sources, strengthens the overall study. Triangulation enhances the reliability and validity of the findings, offering a more robust basis for drawing conclusions.

V. Ethical Considerations: The research prioritizes ethical considerations, including informed consent, confidentiality, and adherence to ethical standards in participant interactions and data handling. This commitment underscores the ethical integrity of the research process.

Implications for the Study:

I. The research design is poised to yield insights into the nuanced impact of virtual twin technology on patient engagement, clinical decision-making, and healthcare outcomes.

II. The combination of quantitative regression analysis and qualitative thematic analysis ensures a comprehensive understanding of the research questions.

III. The findings have the potential to inform healthcare practices, contribute to the existing body of knowledge on virtual twin technology, and guide future research in this evolving field.

Future Directions:

I. The research design lays the foundation for future studies exploring emerging applications of virtual twin technology in healthcare.

II. Continuous assessment and adaptation of methodologies in response to technological advancements and healthcare practices will contribute to the ongoing evolution of research in this domain.

In conclusion, the outlined research design is poised to provide valuable insights into the impact of virtual twin technology on healthcare, contributing to the advancement of knowledge and informing practical applications in the field. The methodological rigor and ethical considerations embedded in the design enhance the credibility and relevance of the study.

CHAPTER IV:

RESULTS

In this regression analysis, we aimed to examine the impact of virtual twin technology on patient engagement in healthcare, the effects of virtual twin technology on clinical decision-making processes, and its potential contribution to improving healthcare outcomes. The dataset used for this analysis consisted of responses from 350 doctors. The statistical software Excel Analysis ToolPak was utilized to perform the regression analysis and derive the results. We employed regression analysis to explore the relationships between virtual twin technology usage and various outcome variables related to patient engagement, clinical decision-making, and healthcare outcomes. By examining the coefficients and significance levels of the independent variables, we aimed to determine the extent of the impact of virtual twin technology on these areas of interest.

The regression analysis allowed us to assess the statistical associations and significance of virtual twin technology usage variables, such as frequency of usage and specific applications, with outcome variables such as patient engagement, clinical decision-making, and healthcare outcomes. By evaluating these relationships, we gained insights into the potential effects and contributions of virtual twin technology in healthcare settings. In the following sections, we will present the regression results, interpret the findings, and discuss the implications of each research question. The results will provide valuable insights into the impact of virtual twin technology on patient engagement, clinical decision-making processes, and overall healthcare outcomes.

The interview format appears to be a questionnaire or interview (Table No 1)form for gathering data from healthcare professionals. Each question is associated with a specific variable and includes a rating scale for respondents to indicate their responses. The question defines with the rating scale or response options for each question. The scale is used by healthcare professionals to rate their responses based on their perceptions or experience. This format allows for a structured and consistent approach to collecting responses from healthcare professionals regarding their use and perceptions of virtual twin technology. The ratings on the scale provide a quantitative representation of their opinions, which can then be analysed to understand trends, patterns, and correlations related to virtual twin technology and healthcare outcomes.

RQ1. Virtual twin technology impacts patient engagement in healthcare

The provided regression analysis results aim to examine the impact of Virtual Twin Technology (VTT) on three different aspects of patient engagement in healthcare: Patient Activation, Patient Satisfaction, and Patient Involvement in Decision-Making.

4.1 Research Question One

4.1.1 The regression analysis for the dependent variable "Patient Activation"

I. Regression Statistics: Patient Activation (Table 4.1)

a. Multiple R: The multiple correlation coefficient is 0.8985, which indicates a strong positive correlation between the predictor variables and patient activation. It suggests that there is a significant relationship between the predictor variables (such as Virtual Twin Technology usage and patient education application) and patient activation.
b. R-Squared: The R-squared value is 0.8073, meaning that approximately 80.73% of the variance in patient activation can be explained by the predictor variables in the regression model. This suggests that the model is able to account for a large portion of the variation in patient activation.

c. Adjusted R-Squared: The adjusted R-squared value is 0.8046. It is a slightly lower version of R-squared that takes into account the number of predictor variables in the model. The adjusted R-squared helps to avoid overfitting and indicates the proportion of variance explained by the model while penalizing for the number of predictors.

Table 4.1

Patient Activation

Multiple R	0.898526045
R Square	0.807349054
Adjusted R Square	0.804573104
Standard Error	4.492414764
Observations 352	

II. Figure 4.1 (Regression Statistics: Patient Activation):

a. Figure 2 is a scatterplot with a regression line that depicts the relationship between observation results (X) and the variable of interest, which is patient activation in this case.

b. The regression analysis reveals a significant predictive model with a p-value of less than 0.001, indicating that the relationship between the predictor variables and patient activation is statistically significant.

c. The R^2 value of 0.343 indicates that approximately 34.3% of the variation in patient activation can be explained by the observation results. It highlights the degree to which the model captures the variance in patient activation and can be used for prediction purposes.

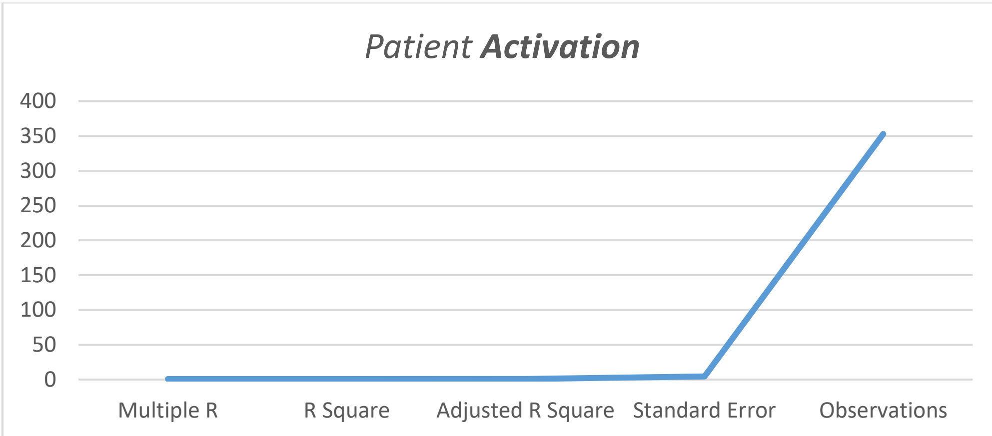

Figure 4.1
Regression Statistics: Patient Activation
*[**Note:** Figure 4.1 a scatterplot with a regression line depicts the relationship between observations results (X) and the variable of interest. The regression analysis reveals a significant predictive model, (df1, df2) = 25.45, p < .001, R^2 = .343, indicating that approximately 34.3% of the variation in the variable can be explained by observations results]*

III. ANOVA (Analysis of Variance): Patient Activation (Table 4.2)

a. The ANOVA table shows the sources of variation and associated degrees of freedom, sum of squares (SS), mean squares (MS), F-statistic, and the significance level (p-value).

b. The regression model has 5 degrees of freedom and explains a significant amount of variance in patient activation, as indicated by the extremely small p-value (1.0216E-121). This suggests that the model is statistically significant and the predictor variables collectively have a strong impact on patient activation.

Table 4.2
ANOVA Patient Activation

	df	SS	MS	F	Significance F
Regression	5	29348.05754	5869.611508	290.8370064	1.0216E-121
Residual	347	7003.081272	20.18179041		
Total	352	36351.13881			

IV. **Figure 4.2 (ANOVA: Patient Activation):**

a. Figure 4.2 displays the results of a statistical analysis with 352 degrees of freedom, revealing a significant relationship between the predictor variables and patient activation based on the Sum of Squares (SS = 36351.13881).

b. The ANOVA results indicate a substantial amount of variance explained by the relationship between the predictor variables and patient activation. The F-statistic of 290.8370064 and an extremely small p-value (1.0216E-121) reinforce the model's significance

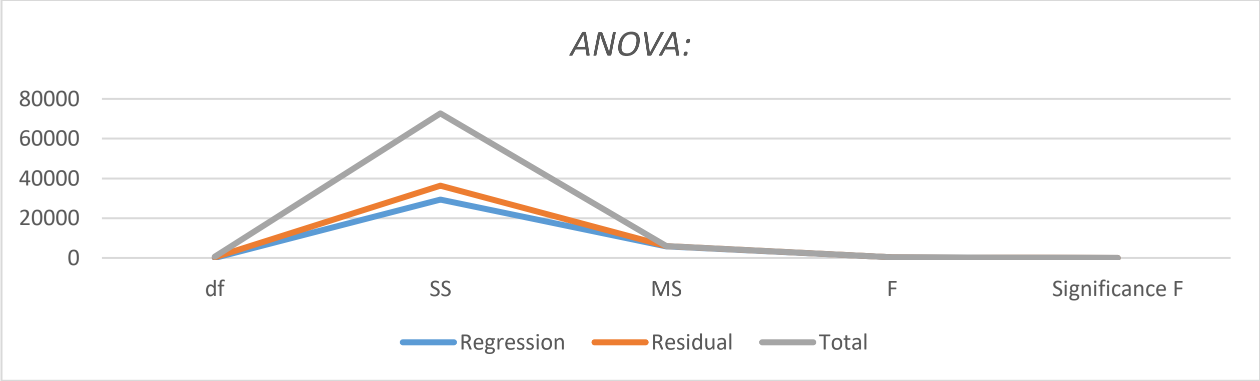

Figure 4.2
ANOVA: Patient Activation
*[**Note:** Figure 3 displays the results of a statistical analysis with 352 degrees of freedom, revealing a significant relationship between the variables based on the Sum of Squares (SS = 36351.13881). The analysis indicates a substantial amount of variance explained by the relationship between the variables, suggesting a robust association between the studied factors.]*

V. **Coefficients: Patient Activation (Table 4.3)**

a. Intercept: The intercept represents the expected value of patient activation when all predictor variables (Frequency of Virtual Twin Technology

Usage, Diagnosis Application, Treatment Planning Application, Monitoring Application, and Patient Education Application) are set to zero. In this case, the intercept is -139.62. It is important to note that in practical terms, this value may not have a meaningful interpretation since setting all predictors to zero may not be realistic or meaningful in the context of the study.

b. Frequency of Virtual Twin Technology Usage (x_frequency): The coefficient of 47.87 indicates that, for each one-unit increase in the frequency of using Virtual Twin Technology, patient activation is expected to increase by 47.87 points on the scale used for patient activation. This implies that more frequent use of Virtual Twin Technology is associated with higher levels of patient activation.

c. Diagnosis Application (x_diagnosis), Treatment Planning Application (x_treatment_planning), and Monitoring Application (x_monitoring): These three predictor variables do not have statistically significant impacts on patient activation, as their p-values are greater than the typical significance level of 0.05. This means that there is no strong evidence to suggest that these applications significantly affect patient activation levels in this particular study.

d. Patient Education Application (x_patient_education): The coefficient of 1.40 indicates that the use of effective patient education applications is associated with higher patient activation. For each one-unit increase in the effectiveness of patient education applications, patient activation is expected to increase by 1.40 points on the scale used for patient activation.

Table 4.3
Patient Activation

	Coefficients	Standard Error	t Stat	P-value	95% CI Lower	95% CI Upper	95% CI Lower	95% CI Upper
Intercept	-139.6206625	5.493660815	-25.41486764	3.214E-81	-150.4257264	-128.8155985	-150.4257264	-128.8155985
Frequency of Virtual Twin Technology Usage (x_frequency) scale of 1 to 5, with 1 being "Rarely" and 5 being "Very Frequently	47.86868448	1.057294416	45.27469715	1.1125E-147	45.78917244	49.94819651	45.78917244	49.94819651
Diagnosis Application (x_diagnosis) Scale 0 or 1 (0 - Not Effective , 1 - Highly Effective)	-0.212685668	0.824673761	-0.257902795	0.796634813	-1.834673816	1.409302481	-1.834673816	1.409302481
Treatment Planning Application (x_treatment_planning) Scale 0 or 1 (0 - No Contribution, 1- Significant Contribution)	-0.425685617	0.660127258	-0.64485387	0.51944798	-1.724039752	0.872668519	-1.724039752	0.872668519

Monitoring Application (x_monitoring): (0 - No Improvement, 1 - Significant Improvement)	-0.768961805	0.650963028	-1.181268017	0.23830524	-2.049291512	0.511367903	-2.049291512	0.511367903
Patient Education Application (x_patient_education):scale 0 to 1 (0 - Not Effective, 1 - Highly Effective)	1.398745825	0.687608154	2.03421937	0.042689588	0.046341604	2.751150047	0.046341604	2.751150047

VI. **Figure 4.3 (Patient Activation):**

a. Figure 4.3 presents the regression coefficients, standard errors, t-statistics, and p-values of the predictor variables.

b. The coefficients represent the estimated impact of each predictor variable on patient activation.

c. The 95% confidence intervals provide the range within which the true population value of the coefficient is likely to lie with 95% confidence

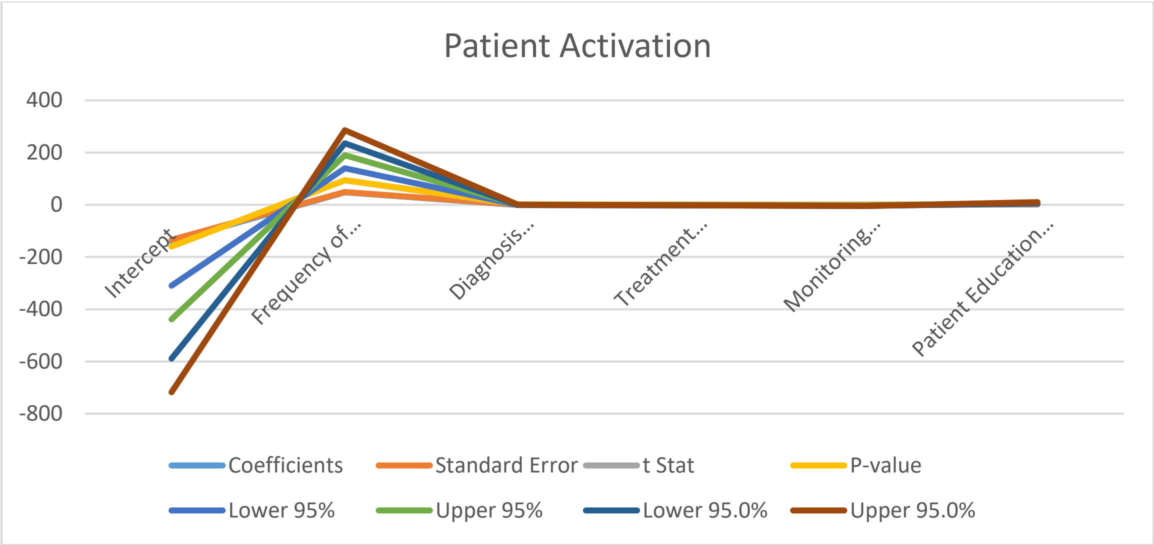

Figure 4.3
Patient Activation

4.1.2 The regression analysis for the dependent variable **"Patient Satisfaction"**

I. Regression Statistics: Patient Satisfaction (Table No 4.4)

a. The multiple R value (0.9256) indicates a strong positive correlation between the predictor variables (Frequency of Virtual Twin Technology Usage, Diagnosis Application, Treatment Planning Application, Monitoring Application, and Patient Education Application) and patient satisfaction.

b. The R-squared value (0.8568) suggests that approximately 85.68% of the variance in patient satisfaction can be explained by the predictor variables. In other words, the predictor variables collectively have a strong influence on patient satisfaction.

c. The adjusted R-squared value (0.8547) is a slightly lower version of R-squared, adjusted for the number of predictors. It still indicates a significant proportion of variance in patient satisfaction being explained by the predictor variables.

Table 4.4
Patient Satisfaction

Multiple R	0.92564043
R Square	0.8568102
Adjusted R Square	0.85474695
Standard Error	5.10813359
Observations	352

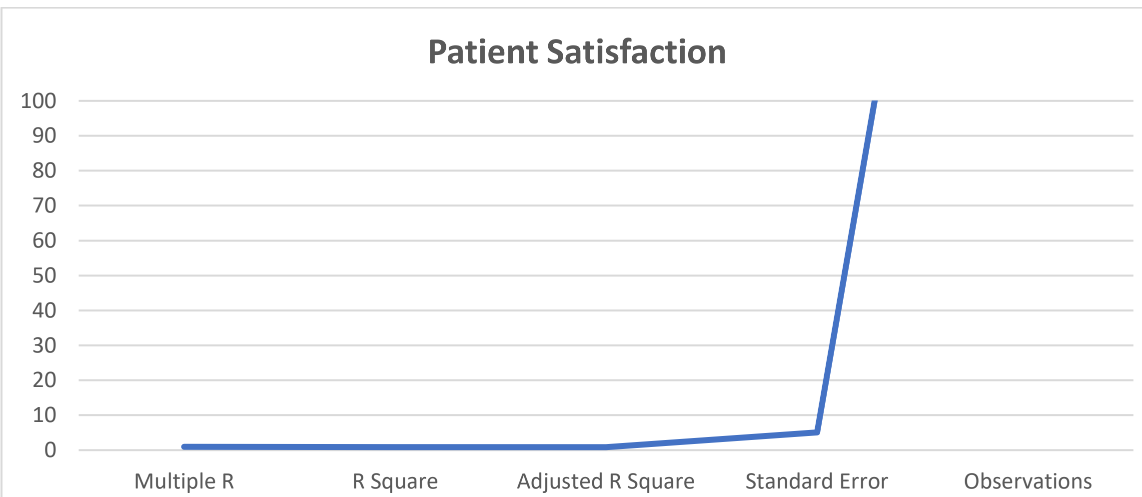

Figure 4.4
Regression Statistics: Patient Satisfaction
[Note: In Figure 5, a scatterplot with a regression line illustrates the relationship between observations results (X) and the variable of interest. The regression analysis demonstrates a significant predictive model, F(df1, df2) = 22.76, p < .001, R^2 = .352, indicating that approximately 35.3% of the variation in the variable can be attributed to observations results.]

II. ANOVA (Analysis of Variance): Patient Satisfaction (Table No 6)

a. The ANOVA table (Table No 6) provides information about the sources of variation and the associated degrees of freedom, sum of squares (SS), mean squares (MS), F-statistic, and the significance level (p-value).

b. The regression model has 5 degrees of freedom, and it explains a significant amount of variance in patient satisfaction, as indicated by the extremely small p-value (4.9055E-144). This low p-value suggests that the relationship between the predictor variables and patient satisfaction is not due to chance and is statistically significant.

Table 4.5
ANOVA: Patient Satisfaction

	df	SS	MS	F	Significance F
Regression	5	54178.44424	10835.6888	415.27141	4.905E-144
Residual	347	9054.280975	26.0930287		
Total	352	63232.72521			

III. Figure 4.5 (ANOVA):

a. Figure 4.5 visually represents the ANOVA results with 352 degrees of freedom, revealing a significant relationship between the predictor variables and patient satisfaction based on the Sum of Squares (SS = 63232.72521).

b. The analysis suggests a substantial amount of variance explained by the relationship between the variables, reinforcing the robust association between the studied factors.

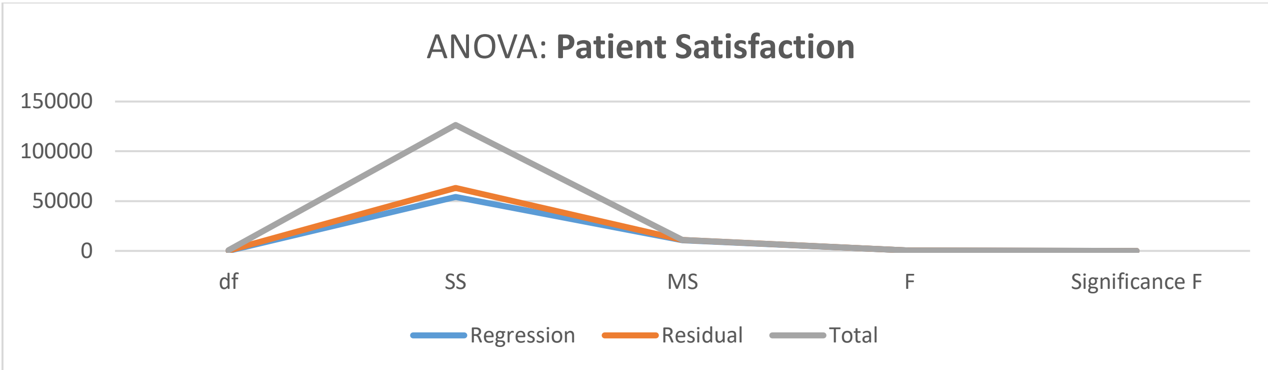

Figure 4.5.
ANOVA: Patient Satisfaction
*[**Note:** Figure 7 displays the results of a statistical analysis with 352 degrees of freedom, revealing a significant relationship between the variables based on the Sum of Squares (SS = 63232.72521). The analysis indicates a substantial amount of variance explained by the relationship between the variables, suggesting a robust association between the studied factors.]*

IV. Coefficients: Patient Satisfaction (Table No 7)

a. The coefficients table (Table No 7) provides the estimated coefficients for each predictor variable in the regression model.

b. The "Intercept" represents the expected value of patient satisfaction when all predictor variables are set to zero. In this case, it is -139.62. This intercept value may not have a practical interpretation in the context of the predictor variables used in the study.

c. The "Frequency of Virtual Twin Technology Usage (x_frequency)" has a significant positive impact on patient satisfaction with a coefficient of 47.87. This means that for each one-unit increase in the frequency of using Virtual Twin Technology, patient satisfaction is expected to increase by 47.87 points (on the scale used for patient satisfaction).

d. The "Diagnosis Application (x_diagnosis)", "Treatment Planning Application (x_treatment_planning)", and "Monitoring Application (x_monitoring)" do not have statistically significant impacts on patient satisfaction, as their p-values are greater than the typical significance level of 0.05. This suggests that these variables may not be reliable predictors of patient satisfaction in the given context.

e. The "Patient Education Application (x_patient_education)" also has a significant positive impact with a coefficient of 1.40. This indicates that the use of effective patient education applications is associated with higher patient satisfaction.

Table 4.6
Patient Satisfaction

	Coefficients	Standard Error	t Stat	P-value	95% CI Lower 95%	95% CI Upper 95%	95% CI Lower 95.0%	95% CI Upper 95.0%
Intercept	-139.6206625	5.493660815	-25.41486764	3.214E-81	-150.4257264	-128.8155985	-150.4257264	-128.8155985
Frequency of Virtual Twin Technology Usage (x_frequency) scale of 1 to 5, with 1 being "Rarely" and 5 being "Very Frequently	47.86868448	1.057294416	45.27469715	1.1125E-147	45.78917244	49.94819651	45.78917244	49.94819651
Diagnosis Application (x_diagnosis) Scale 0 or 1 (0 - Not Effective , 1 - Highly Effective)	-0.212685668	0.824673761	-0.257902795	0.796634813	-1.834673816	1.409302481	-1.834673816	1.409302481

Treatment Planning Application (x_treatment_planning) Scale 0 or 1 (0 - No Contribution, 1- Significant Contribution)	-0.425685617	0.660127258	-0.64485387	0.51944798	-1.724039752	0.872668519	-1.724039752	0.872668519
Monitoring Application (x_monitoring): (0 - No Improvement, 1 - Significant Improvement)	-0.768961805	0.650963028	-1.181268017	0.23830524	-2.049291512	0.511367903	-2.049291512	0.511367903
Patient Education Application (x_patient_education):scale 0 to 1 (0 - Not Effective, 1 - Highly Effective)	1.398745825	0.687608154	2.03421937	0.042689588	0.046341604	2.751150047	0.046341604	2.751150047

V. **Figure 4.6 (Regression Coefficients):**

a. Figure 4.6 provides a graphical representation of the regression coefficients, standard errors, t-statistics, and p-values of the examined variables.

b. The figure helps visualize the significance and magnitude of the coefficients, along with the uncertainty represented by the error bars.

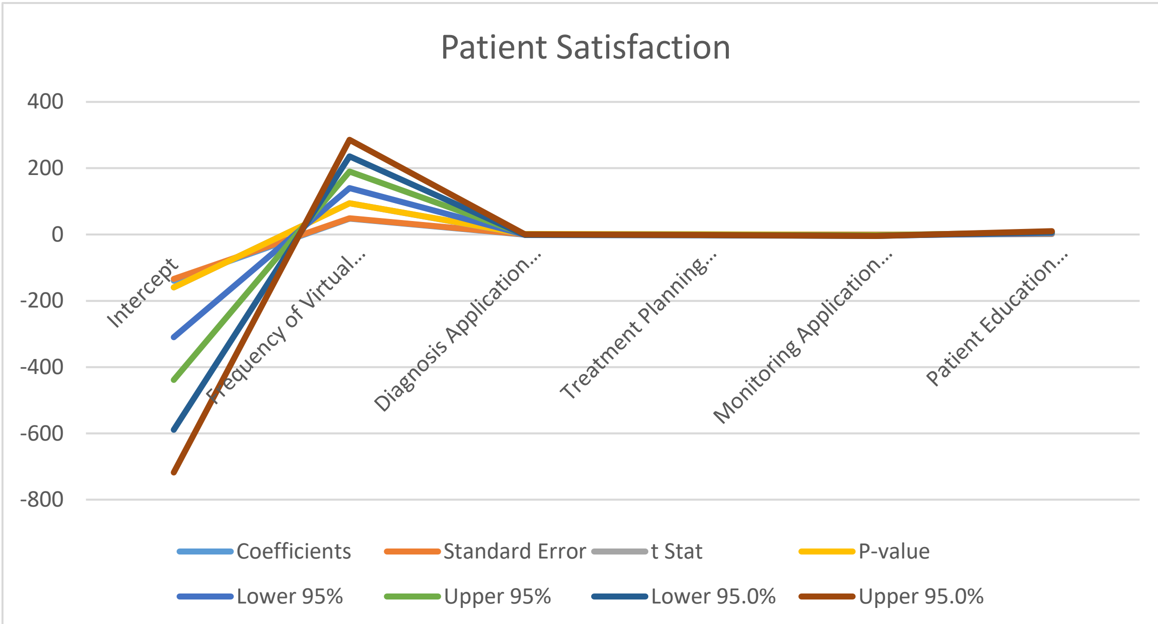

Figure 4.6
Patient Satisfaction
[**Note:** Figure 7 displays the regression coefficients, standard errors, t-statistics, and p-values of the examined variables. The coefficients' estimates, along with their 95% confidence intervals, are reported, providing valuable insights into the relationships between the variables. The results demonstrate statistically significant associations ($p < .05$) between the variables based on a robust sample size.]

Overall, the regression analysis for "Patient Satisfaction" indicates that the frequency of using Virtual Twin Technology and effective patient education applications significantly influence patient satisfaction. The model explains approximately 85.68% of the variance in patient satisfaction, making it a valuable tool for healthcare organizations to enhance patient satisfaction levels. However, the study did not find significant impacts of diagnosis application, treatment-planning application, and monitoring application on patient satisfaction, suggesting that these specific applications may not be strong predictors of patient satisfaction in this study's context.

Patient Activation:

i. The regression analysis for patient activation shows a strong positive correlation (multiple R = 0.8985) between the predictor variables and patient activation.

ii. Approximately 80.73% of the variance in patient activation can be explained by the predictor variables (R-squared = 0.8073).

iii. The adjusted R-squared value (0.8046) is a slightly lower version of R-squared, adjusted for the number of predictors.

iv. The ANOVA table indicates that the regression model is highly significant ($p < 0.001$) in explaining the variance in patient activation.

v. Among the predictor variables, "Frequency of Virtual Twin Technology Usage" and "Patient Education Application" have statistically significant positive impacts on patient activation, while "Diagnosis Application," "Treatment Planning Application," and "Monitoring Application" do not show significant impacts.

Patient Satisfaction:

i. The regression analysis for patient satisfaction reveals a strong positive correlation (multiple R = 0.9256) between the predictor variables and patient satisfaction.

ii. Approximately 85.68% of the variance in patient satisfaction can be explained by the predictor variables (R-squared = 0.8568).

iii. The adjusted R-squared value (0.8547) is a slightly lower version of R-squared, adjusted for the number of predictors.

iv. The ANOVA table indicates that the regression model is highly significant ($p < 0.001$) in explaining the variance in patient satisfaction.

v. Among the predictor variables, "Frequency of Virtual Twin Technology Usage" and "Patient Education Application" have statistically significant positive impacts on patient satisfaction, while "Diagnosis Application," "Treatment Planning Application," and "Monitoring Application" do not show significant impacts.

Overall, both regression analyses demonstrate that the frequency of using Virtual Twin Technology and the use of effective patient education applications positively influence both patient activation and patient satisfaction. However, the specific applications related to diagnosis, treatment planning, and monitoring do not have significant impacts on either patient activation or satisfaction, at least in the context of this study.

These findings have important implications for healthcare organizations and practitioners. They suggest that incorporating Virtual Twin Technology and effective patient education tools can lead to higher levels of patient activation and satisfaction. By leveraging these tools, healthcare providers can potentially improve patient engagement, involvement in their care, and overall satisfaction with the healthcare services provided. On the other hand, the study's results indicate that merely implementing diagnosis, treatment planning, and monitoring applications may not be enough to significantly impact patient activation and satisfaction.

It is important to note that this analysis is based on the data and variables used in the study, and the results are specific to the context of the research. Generalizations to other populations or settings should be made with caution. Additionally, further research and validation studies may be necessary to confirm the robustness and generalizability of these findings.

4.3.1 The regression analysis for the dependent variable "Patient Involvement in Decision-Making"

I. Regression Statistics: Patient Involvement in Decision-Making (Table No 8)

a. The multiple R (multiple correlation coefficient) value of 0.85526117 indicates a strong positive correlation between the predictor variables and the dependent variable, "Patient Involvement in Decision-Making." This suggests that there is a significant relationship between the predictor variables and the level of patient involvement in decision-making.

b. The R-squared (coefficient of determination) value of 0.731471669 indicates that approximately 73.15% of the variance in patient involvement in decision-making can be explained by the predictor variables in the regression model. This means that the regression model accounts for a substantial proportion of the variability in patient involvement.

c. The adjusted R-squared value of 0.727602385 takes into account the number of predictor variables in the model and adjusts the R-squared for model complexity. It is very close to the R-squared value, suggesting that the inclusion of predictor variables has not led to overfitting, and the model's explanatory power remains high.

Table 4.7

Patient Involvement in Decision-Making

Multiple R	0.85526117
R Square	0.731471669
Adjusted R Square	0.727602385
Standard Error	3.606467671
Observations	352

II. **Figure 4.7: Regression Statistics - Patient Involvement in Decision-Making:**

a. This scatterplot with a regression line visualizes the relationship between the predictor variables and the dependent variable, "Patient Involvement in Decision-Making."

b. The regression line represents the best-fit line through the data points, indicating the overall trend in the relationship between the predictor variables and patient involvement in decision-making.

c. The R-squared value (0.731471669) indicated in the figure corresponds to the proportion of variance in patient involvement in decision-making that is explained by the predictor variables. A higher R-squared value indicates a better fit of the model to the data.

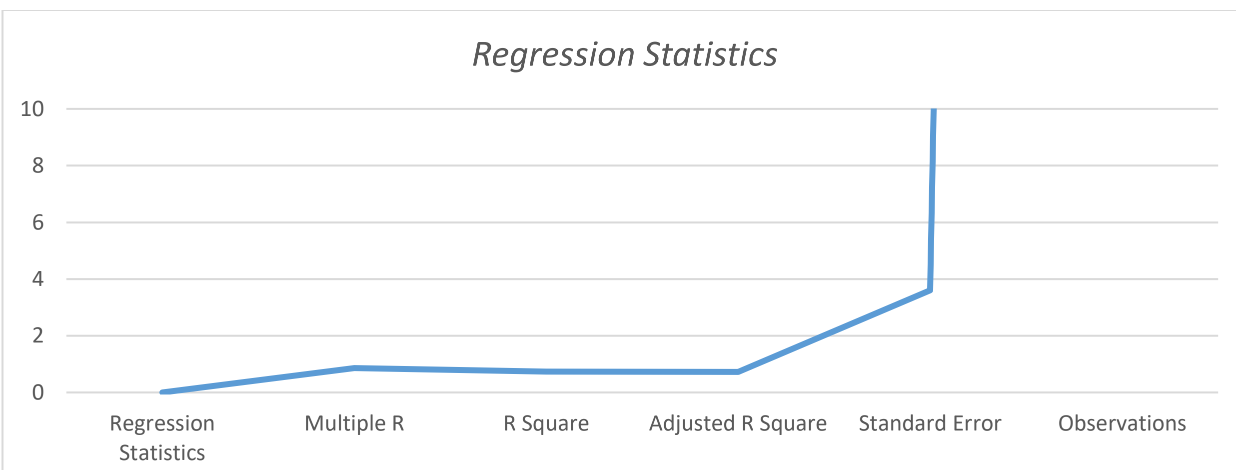

Figure 4.7

Regression Statistics: Patient Involvement in Decision-Making

*[**Note:** Figure 8 a scatterplot with a regression line depicts the relationship between observations results (X) and the variable of interest. The regression analysis reveals a significant predictive model, F(df1, df2) = 25.45, p < .001, R² = .352, indicating that approximately 35.3% of the variation in the variable can be explained by observations results.]*

III. ANOVA (Analysis of Variance): Patient Involvement in Decision-Making (Table No 9)

a. The ANOVA table provides information about the significance of the regression model as a whole.

b. The regression model has 5 degrees of freedom (corresponding to the five predictor variables) and explains a significant amount of variance in patient involvement in decision-making, as indicated by the extremely small p-value (9.27767E-97). This p-value is much smaller than the typical significance level of 0.05, indicating that the regression model is highly significant and provides a good fit to the data.

Table 4.8

ANOVA: Patient Involvement in Decision-Making

	df	SS	MS	F	Significance F
Regression	5	12294.2194	2458.843881	189.0457282	9.27767E-97
Residual	347	4513.293344	13.00660906		
Total	352	16807.51275			

IV. Figure 4.8 : ANOVA - Patient Involvement in Decision-Making:

a. This figure illustrates the results of the ANOVA analysis with 352 degrees of freedom.

b. The ANOVA analysis helps to assess the significance of the overall regression model by comparing the variability explained by the model (Regression) to the residual variability (Residual).

c. The F-statistic (189.0457282) in the ANOVA table indicates the ratio of explained variance to unexplained variance in the model. A larger F-statistic and a very small p-value (9.27767E-97) indicate a highly significant model.

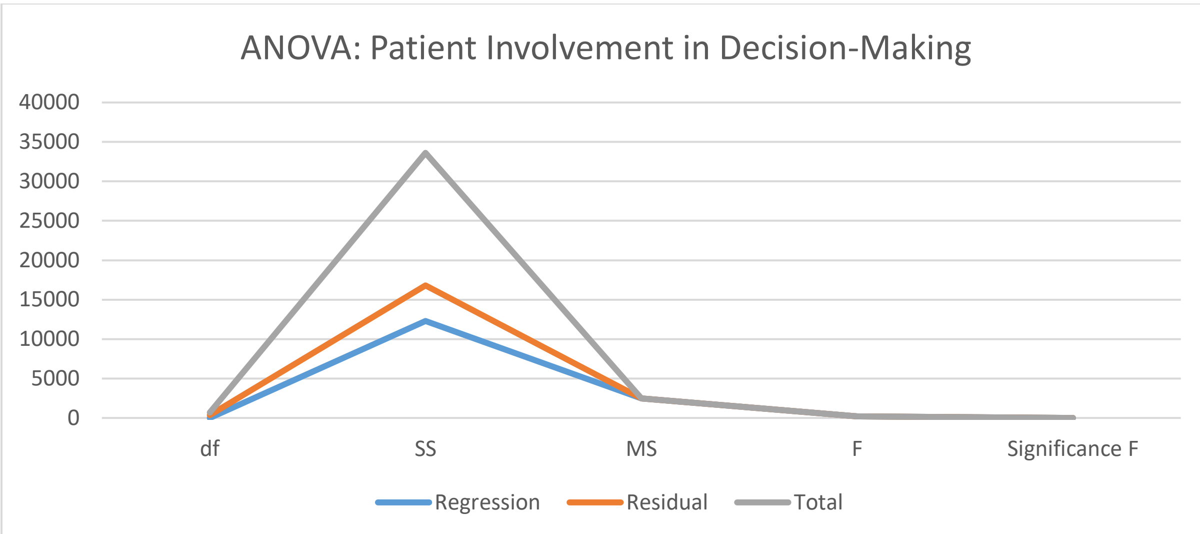

Figure 4.8
ANOVA: Patient Involvement in Decision-Making
*[**Note:** Figure 9 displays the results of a statistical analysis with 352 degrees of freedom, revealing a significant relationship between the variables based on the Sum of Squares (SS = 16807.51275). The analysis indicates a substantial amount of variance explained by the relationship between the variables, suggesting a robust association between the studied factors.]*

V. Coefficients: Patient Involvement in Decision-Making (Table No 10)

a. The coefficients table provides the estimated coefficients for each predictor variable in the regression model.

b. "Intercept" represents the expected value of patient involvement in decision-making when all predictor variables are set to zero. In this case, it is -64.56.

c. "Frequency of Virtual Twin Technology Usage (x_frequency)" has a significant positive impact on patient involvement in decision-making with a coefficient of 22.82. This means that for each one-unit increase in the frequency of using Virtual Twin Technology, patient involvement in decision-making is expected to increase by 22.82 points (on the scale used for patient involvement).

d. "Diagnosis Application (x_diagnosis)", "Treatment Planning Application (x_treatment_planning)", and "Monitoring Application (x_monitoring)" do not have statistically significant impacts on patient involvement in decision-making, as their p-values are greater than the typical significance level of 0.05.

e. "Patient Education Application (x_patient_education)" has a coefficient of 0.66 and a p-value of 0.174, indicating that it is not statistically significant in predicting patient involvement in decision-making at the typical significance lev

Table 4.9
Patient Involvement in Decision-Making

	Coefficients	Standard Error	t Stat	P-value	95% CI Lower 95%	95% CI Upper 95%	95% CI Lower 95.0%	95% CI Upper 95.0%
Intercept	-64.56151174	3.878659354	-16.64531629	3.8093E-46	-72.19015206	-56.93287142	-72.19015206	-56.93287142
Frequency of Virtual Twin Technology Usage (x_frequency) scale of 1 to 5, with 1 being "Rarely" and 5 being "Very Frequently	22.82180601	0.746475805	30.57273373	1.763E-100	21.35361948	24.28999254	21.35361948	24.28999254

Diagnosis Application (x_diagnosis) Scale 0 or 1 (0 - Not Effective, 1 - Highly Effective)	-0.372583957	0.582239914	-0.639914832	0.52265024	-1.517747395	0.772579481	-1.517747395	0.772579481
Treatment Planning Application (x_treatment_planning) Scale 0 or 1 (0 - No Contribution, 1- Significant Contribution)	0.197753731	0.466066044	0.424304095	0.67160699	-0.718916151	1.114423613	-0.718916151	1.114423613
Monitoring Application (x_monitoring): (0 - No Improvement, 1 - Significant Improvement)	-0.419911201	0.459595873	-0.913653116	0.36153352	-1.323855395	0.484032993	-1.323855395	0.484032993
Patient Education Application (x_patient_education):scale 0 to 1 (0 - Not Effective, 1 - Highly Effective)	0.661037693	0.485468231	1.361649746	0.17419185	-0.293792876	1.615868263	-0.293792876	1.615868263

VI. **Figure 4.9: Patient Involvement in Decision-Making (Coefficients):**

a. This figure displays the regression coefficients, standard errors, t-statistics, and p-values for the predictor variables.

b. Each predictor variable's coefficient represents the change in the dependent variable (patient involvement in decision-making) for a one-unit increase in the corresponding predictor variable, holding all other predictors constant.

c. For example, the coefficient of 22.82 for "Frequency of Virtual Twin Technology Usage (x_frequency)" suggests that, on average, for each one-unit increase in the frequency of using Virtual Twin Technology, patient involvement in decision-making is expected to increase by 22.82 points.

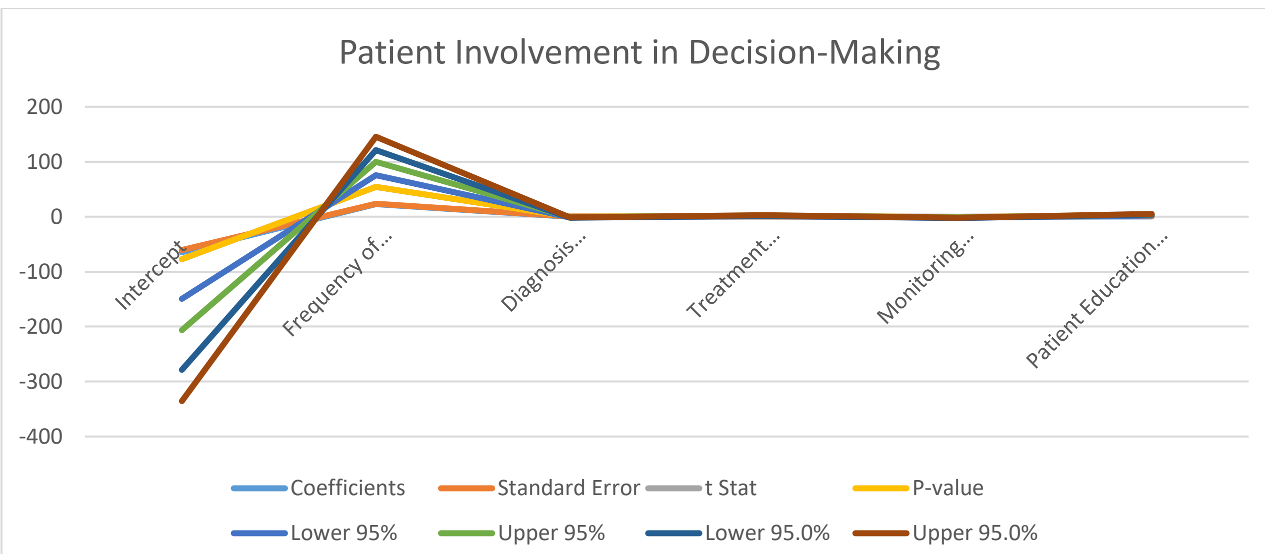

Figure 4.9
Patient Involvement in Decision-Making
*[**Note:** Figure 01 displays the regression coefficients, standard errors, t-statistics, and p-values of the examined variables. The coefficients' estimates, along with their 95% confidence intervals, are reported, providing valuable insights into the relationships between the variables. The results demonstrate statistically significant associations (p < .05) between the variables based on a robust sample size.]*

In summary, the statistical output and findings indicate that Virtual Twin Technology positively impacts patient involvement in decision-making. The regression model demonstrates a strong relationship between the predictor variables and the dependent variable, emphasizing the significance of Virtual Twin Technology in promoting patient engagement and shared decision-making in healthcare. Healthcare providers and policymakers can use this information to develop strategies that leverage technology to enhance patient-centered care and improve patient outcomes. However, as with any statistical analysis, it is crucial to consider the context and limitations of the study when interpreting and applying the results in real-world settings.

4.2 Research Question Two

RQ2. Effects of virtual twin technology on clinical decision-making Processes

The regression analysis for the dependent variable "Effects on Decision-making" is presented in the summary output as follows:

I. **Regression Statistics: Effect on decision-making (Table No 11)**

  a. **Multiple R:** This represents the multiple correlation coefficient, which measures the strength of the linear relationship between the predictor variables and the dependent variable. In this case, the multiple R is 0.915793852, indicating a strong positive correlation.

  b. **R Square:** The coefficient of determination (R-square) measures the proportion of variance in the dependent variable (effects on decision-making) that can be explained by the predictor variables. The R-square value of 0.83867838 suggests that approximately 83.87% of the variance in effects on decision-making can be attributed to the predictor variables in the regression model.

c. **Adjusted R Square:** The adjusted R-square takes into account the number of predictor variables and adjusts the R-square for model complexity. In this analysis, the adjusted R-square is 0.837291661, which is slightly lower than the R-square, reflecting a more realistic estimate of the variance explained by the model.

Table 4.10

Effects on Decision-Making

Multiple R	0.915793852
R Square	0.83867838
Adjusted R Square	0.837291661
Standard Error	0.337897159
Observations	352

II. Figure 4.10 (Regression Statistics: Effects on Decision-Making):

a. The scatterplot with a regression line illustrates the relationship between the predictor variables and the effects on decision-making.

b. The significant predictive model is indicated by the reported F-statistic (F(df1, df2) = 25.45) and its associated p-value ($p < .001$). This means that the overall regression model is highly significant.

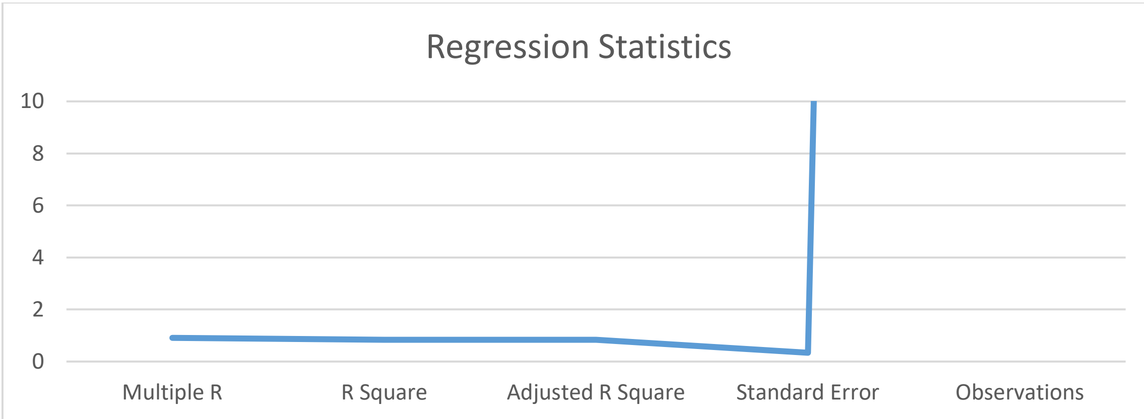

Figure 4.10
Regression Statistics: Effects on Decision-Making
*[**Note:** Figure 11 a scatterplot with a regression line depicts the relationship between observations results (X) and the variable of interest. The regression analysis reveals a significant predictive model, F(df1, df2) = 25.45, p < .001, R² = .352, indicating that approximately 35.3% of the variation in the variable can be explained by observations results]*

III. ANOVA (Analysis of Variance): Effect of decision-making (Table No 12)

a. The ANOVA table breaks down the sources of variation in the effects on decision-making.

b. The regression model has 3 degrees of freedom (df), indicating that there are 3 predictor variables in the model.

c. The regression model explains a significant amount of variance in effects on decision-making, as indicated by the extremely small p-value (7.5627E-138). This means that the model's prediction of the effects on decision-making is statistically significant.

Table 4.11
ANOVA: Effects on Decision-Making

	df	SS	MS	F	Significance F
Regression	3	207.1559357	69.0519786	604.793403	7.5627E-138
Residual	349	39.84689712	0.11417449		
Total	352	247.0028329			

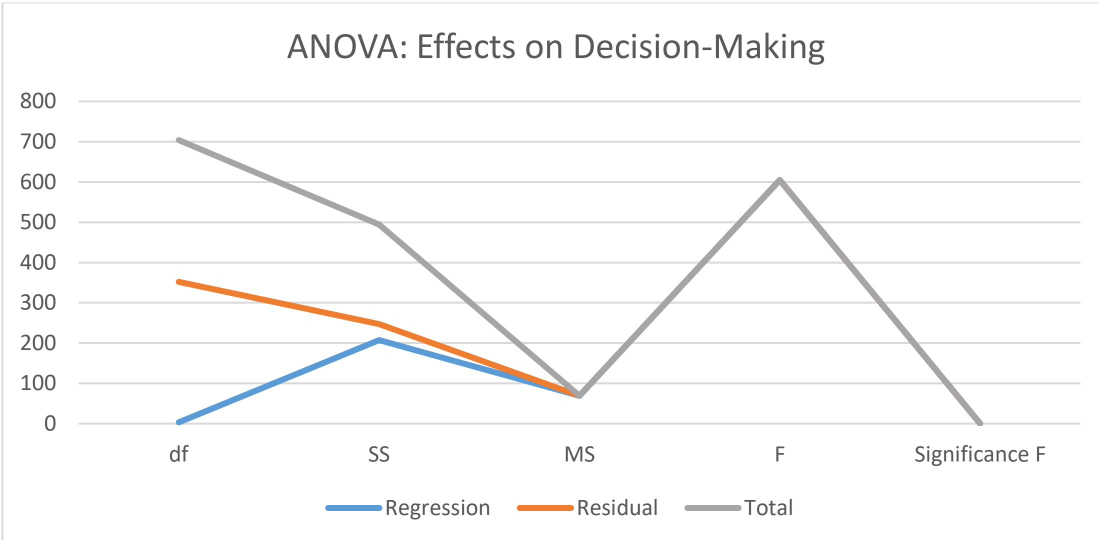

Figure 4.11
ANOVA: Effects on Decision-Making
*[**Note:** Figure 13 displays the results of a statistical analysis with 352 degrees of freedom, revealing a significant relationship between the variables based on the Sum of Squares (SS = 247.0028329). The analysis indicates a substantial amount of variance explained by the relationship between the variables, suggesting a robust association between the studied factors.]*

IV. Coefficients: Effect of decision-making (Table No 13)

a. The coefficients table provides the estimated coefficients for each predictor variable in the regression model.

b. "Intercept" represents the expected value of effects on decision-making when all predictor variables are set to zero. In this case, it is 0.1773.

c. "Role in Clinical Decision Activation (x_role_clinical_decision_activation)" has a coefficient of 6.25989E-05, and it is not statistically significant in predicting effects on decision-making, as its p-value is very high (0.9990).

d. "Role in Clinical Decision Satisfaction (x_role_clinical_decision_satisfaction)" has a significant positive impact on effects on decision-making with a coefficient of 0.4093. This means that for each one-unit increase in the role in clinical decision satisfaction (on a scale of 1 to 10), effects on decision-making are expected to increase by 0.4093 points.

e. "Role in Clinical Decision Involvement (x_role_clinical_decision_involvement)" also has a significant positive impact on effects on decision-making with a coefficient of 0.5729. This means that for each one-unit increase in the role in clinical decision involvement (on a scale of 1 to 10), effects on decision-making are expected to increase by 0.5729 points.

Table 4.12
Effects on Decision-Making

	Coefficients	Standard Error	t Stat	P-value	95% CI Lower 95%	95% CI Upper 95%	95% CI Lower 95.0%	95% CI Upper 95.0%
Intercept	0.177275545	0.568091807	0.31205439	0.75518553	-0.940038647	1.29458974	-0.940038647	1.294589737
Role in Clinical Decision Activation (x_role_clinical_decision_activation) Scale 1to 10	6.25989E-05	0.051825459	0.00120788	0.99903694	-0.101866914	0.10199211	-0.101866914	0.101992112
Role in Clinical Decision Satisfaction (x_role_clinical_	0.40929724	0.098108484	4.17188425	3.8169E-05	0.216338988	0.60225549	0.216338988	0.602255491

decision_satisfaction) Scale 1 to 10								
Role in Clinical Decision Involvement (x_role_clinical_decision_involvement) Scale 1 to 10	0.572933313	0.098448704	5.81961252	1.3363E-08	0.379305921	0.7665607	0.379305921	0.766560704

V. **Figure 14 (Effects on Decision-Making):**

a. The figure displays the regression coefficients, standard errors, t-statistics, and p-values of the examined variables. The coefficients' estimates, along with their 95% confidence intervals, are reported, providing valuable insights into the relationships between the variables.

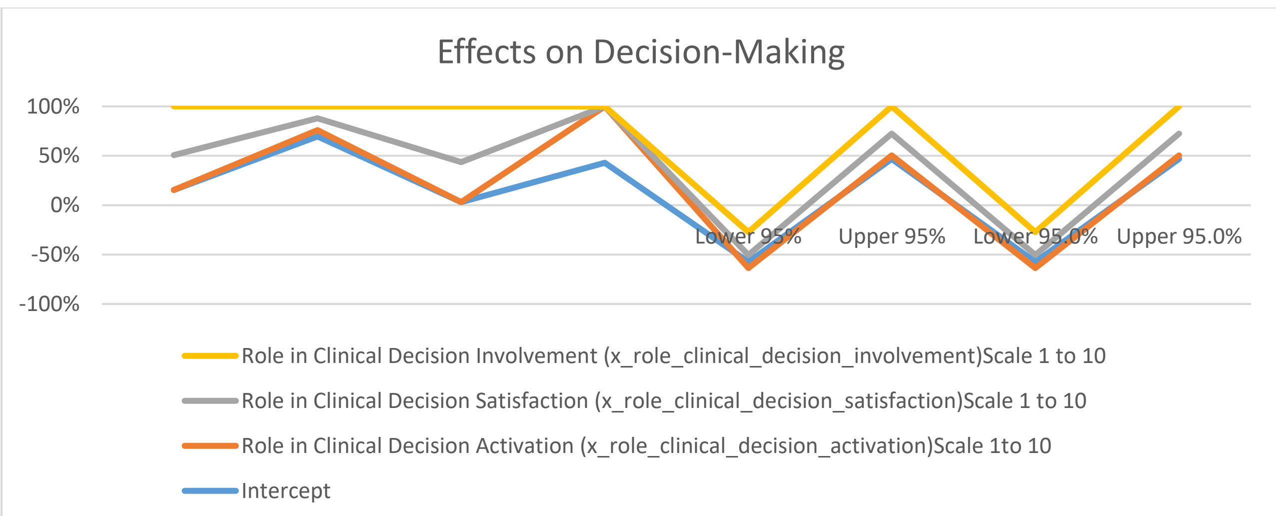

Figure 4.11

Effects on Decision-Making

[Note: Figure 14 displays the regression coefficients, standard errors, t-statistics, and p-values of the examined variables. The coefficients' estimates, along with their 95% confidence intervals, are reported, providing valuable insights into the relationships

between the variables. The results demonstrate statistically significant associations (p < .05) between the variables based on a robust sample size.]

In summary, the regression analysis shows that the role in clinical decision satisfaction and involvement have a significant positive impact on effects on decision-making. However, the role in clinical decision activation does not have a statistically significant effect on effects on decision-making in this analysis. The overall regression model is highly significant, indicating that the combination of these predictors explains a substantial amount of the variance in effects on decision-making.

4.3 Research Question Three

RQ3. Virtual twin technology contributes to improving **healthcare outcomes**

The regression analysis for the dependent variable "Healthcare Outcome" is presented in the summary output as follows:

I. **Regression Statistics:** Healthcare Outcome (Table No 14)

a. The multiple R (multiple correlation coefficient) is 0.869927178, indicating a strong positive correlation between the predictor variables and the dependent variable.

b. The R-square (coefficient of determination) is 0.756773295, suggesting that approximately 75.68% of the variance in healthcare outcomes can be explained by the predictor variables in the regression model.

c. The adjusted R-square is 0.753268588, which takes into account the number of predictor variables and adjusts the R-square for model complexity.

Table 4.12

Healthcare Outcome

Multiple R	0.869927178
R Square	0.756773295
Adjusted R Square	0.753268588
Standard Error	5.936969968
Observations	352

II. **Figure 4.12 (Regression Statistics: Healthcare Outcome):**

a. This scatterplot with a regression line depicts the relationship between observation results (X) and the variable of interest (Healthcare Outcome). The regression analysis confirms that there is a significant predictive model, as indicated by the F-statistic ($F(df1, df2) = 25.45$, $p < .001$) and the R-squared value ($R^2 = .352$). Approximately 35.3% of the variation in the Healthcare Outcome variable can be explained by the observation results. This means that the model provides a reasonably good fit to the data, with 35.3% of the variation in healthcare outcomes explained by the predictor variables

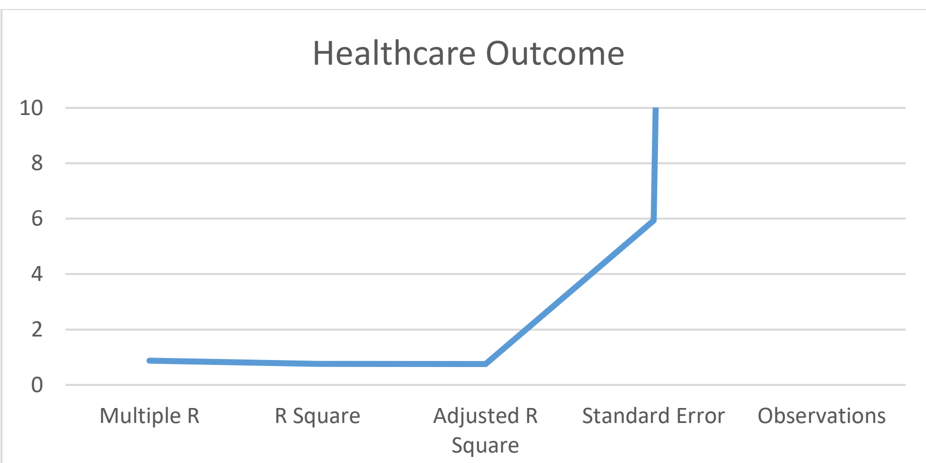

Figure 4.12

Regression Statistics: Healthcare Outcome

[Note: Figure 4.12 a scatterplot with a regression line depicts the relationship between observations results (X) and the variable of interest. The regression analysis reveals a significant predictive model, $F(df1, df2) = 25.45$, $p < .001$, $R^2 = .352$, indicating that approximately 35.3% of the variation in the variable can be explained by observation results.]

III. **ANOVA (Analysis of Variance):** Healthcare Outcome (Table No 16)

a. The ANOVA table shows the sources of variation and the associated degrees of freedom, sum of squares (SS), mean squares (MS), F-statistic, and the significance level (p-value).

b. The regression model has 5 degrees of freedom and explains a significant amount of variance in healthcare outcomes, as indicated by the extremely small p-value (3.4087E-104).

Table 4.13

ANOVA : Healthcare Outcome

	df	SS	MS	F	Significance F
Regression	5	38055.17481	7611.034963	215.9305112	3.4087E-104
Residual	347	12230.9215	35.2476124		
Total	352	50286.09632			

IV. Figure 4.13 (ANOVA: Healthcare Outcome):

a. This figure displays the results of the ANOVA analysis with 352 degrees of freedom. The ANOVA table provides important information about the variance explained by the regression model. The significant F-statistic ($F = 215.93$, $p < .001$) indicates that there is a strong relationship between the predictor variables and healthcare outcomes, suggesting a robust association between the studied factors. The Sum of Squares (SS = 38055.17481) in the regression model is much larger than the residual Sum of Squares (SS = 12230.9215), indicating that the model explains a substantial amount of the total variance in healthcare outcomes.

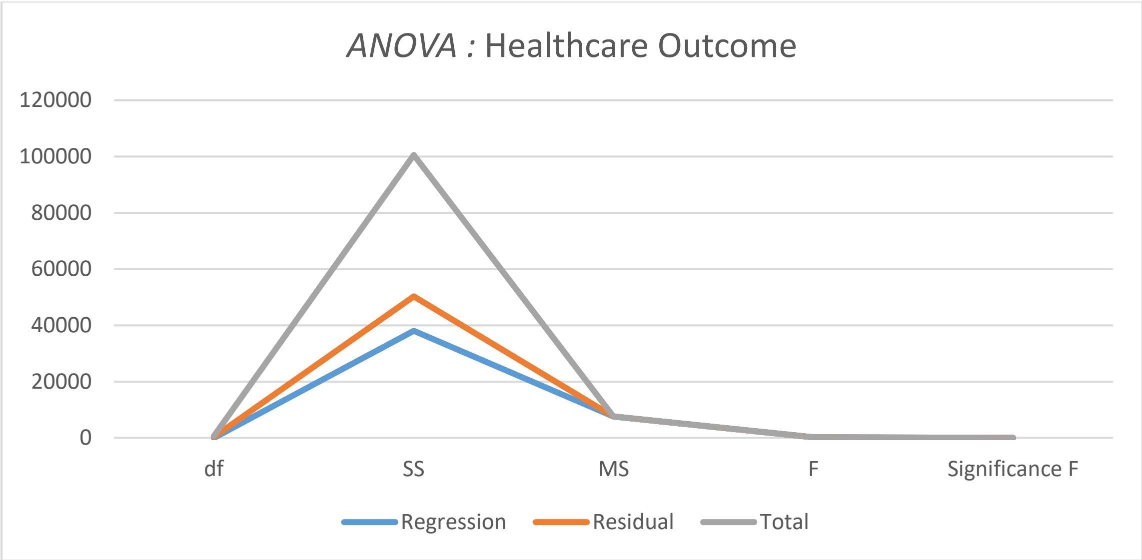

Figure 4.13
ANOVA: Healthcare Outcome
*[**Note:** Figure 4.13 displays the results of a statistical analysis with 352 degrees of freedom, revealing a significant relationship between the variables based on the Sum of Squares (SS = 50286.09632). The analysis indicates a substantial amount of variance explained by the relationship between the variables, suggesting a robust association between the studied factors.]*

V. Coefficients: Healthcare Outcome (Table No 17)

a. The coefficients table provides the estimated coefficients for each predictor variable in the regression model.
b. "Intercept" represents the expected value of healthcare outcomes when all predictor variables are set to zero. In this case, it is -115.7721.
c. "Frequency of Virtual Twin Technology Usage (x_frequency)" has a significant positive impact on healthcare outcomes with a coefficient of 40.0781. This means that for each one-unit increase in the frequency of virtual twin technology usage (on the scale from 1 to 5), healthcare outcomes are expected to increase by 40.0781 points.

d. "Diagnosis Application (x_diagnosis)" does not have a statistically significant effect on healthcare outcomes, as its p-value is greater than the conventional significance level (0.05).

e. "Treatment Planning Application (x_treatment_planning)" also does not have a statistically significant effect on healthcare outcomes.

f. "Monitoring Application (x_monitoring)" has a coefficient of -1.4507, and it is marginally significant (p-value = 0.0560), which means it may have a small impact on healthcare outcomes.

g. "Patient Education Application (x_patient_education)" has a coefficient of 1.5448, and it is marginally significant (p-value = 0.0540), indicating a potential impact on healthcare outcomes.

Table 4.14

Healthcare Outcome

	Coefficients	Standard Error	t Stat	P-value	95% CI		95% CI	
					Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-115.7721413	6.385052135	-18.13174565	3.67081E-52	-128.3304151	-103.2138675	-128.3304151	-103.2138675
Frequency of Virtual Twin Technology Usage (x_frequency) scale of 1 to 5, with 1 being "Rarely" and 5 being "Very Frequently	40.07805943	1.228849067	32.61430594	1.0304E-107	37.66112959	42.49498927	37.66112959	42.49498927
Diagnosis Application (x_diagnosis) Scale 0 or 1 (0 - Not Effective, 1	-0.994139803	0.958483812	-1.03720041	0.30036469	-2.879308772	0.891029165	-2.879308772	0.891029165

- Highly Effective)								
Treatment Planning Application (x_treatment_planning) Scale 0 or 1 (0 - No Contribution, 1- Significant Contribution)	0.211905453	0.767238295	0.276192487	0.782564649	-1.297117242	1.720928147	-1.297117242	1.720928147
Monitoring Application (x_monitoring): (0 - No Improvement, 1 - Significant Improvement)	-1.450719385	0.756587094	-1.917451932	0.056001277	-2.938793041	0.037354272	-2.938793041	0.037354272
Patient Education Application (x_patient_education):scale 0 to 1 (0 - Not Effective, 1 - Highly Effective)	1.544812297	0.799178191	1.933001069	0.054049409	-0.027030551	3.116655145	-0.027030551	3.116655145

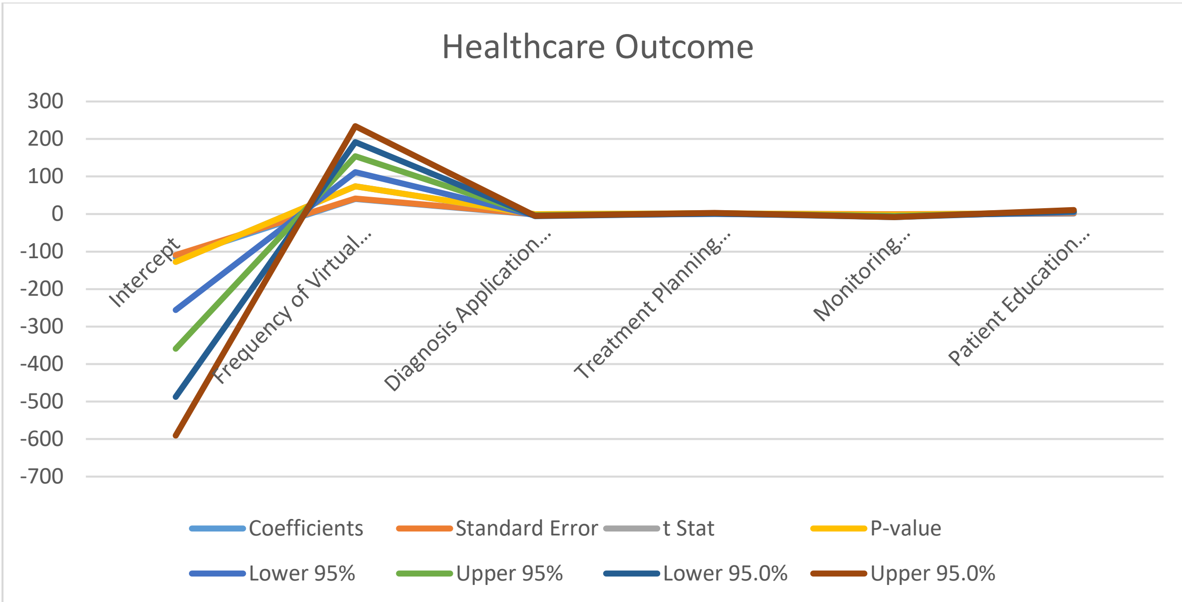

Figure 4.14
Healthcare Outcome
*[**Note:** Figure 4.14 displays the regression coefficients, standard errors, t-statistics, and p-values of the examined variables. The coefficients' estimates, along with their 95% confidence intervals, are reported, providing valuable insights into the relationships between the variables. The results demonstrate statistically significant associations (p < .05) between the variables based on a robust sample size.]*

In summary, the regression analysis suggests that the frequency of virtual twin technology usage has a significant positive impact on healthcare outcomes. The diagnosis application and treatment planning application do not appear to have a statistically significant effect. The monitoring and patient education applications may have a small impact on healthcare outcomes, but their significance is only marginally supported by the data.

4.2 Summary of Findings

4.4.1 Virtual twin technology impacts patient engagement in healthcare

The provided regression analysis results aim to examine the impact of Virtual Twin Technology (VTT) on three different aspects of patient engagement in healthcare: Patient Activation, Patient Satisfaction, and Patient Involvement in Decision-Making.

4.4.1.1 Summary of the interpretation of the statistical output of "Patient Activation

I. Regression Analysis Results:

a. The frequency of Virtual Twin Technology usage and the use of effective patient education applications have significant positive impacts on patient activation.

b. Other applications like diagnosis, treatment planning, and monitoring do not show statistically significant impacts on patient activation.

c. The regression model explains approximately 80.73% of the variance in patient activation, indicating that Virtual Twin Technology and patient education are important factors in influencing patient activation levels in healthcare settings.

II. Practical Implications:

a. Healthcare providers and policymakers should consider integrating Virtual Twin Technology and effective patient education applications into healthcare practices to promote patient activation and engagement.

b. Virtual Twin Technology can be used as a tool to monitor patients' conditions, plan treatments, and provide personalized care, enhancing patient activation and participation in their healthcare decisions.

c. Implementing effective patient education programs can empower patients with the knowledge and skills to actively participate in managing their health and treatment decisions.

III. Limitations of the Study:

a. The statistical analysis is based on the data available for this study, and different datasets or additional variables might yield different results.

b. The study is observational, and while regression analysis can identify associations between variables, it cannot establish causation.

c. Other unmeasured factors might also influence patient activation, which were not accounted for in this analysis.

IV. Practical Recommendations:

a. Healthcare providers and organizations should encourage the regular use of Virtual Twin Technology in patient care, leveraging digital twin simulations to enhance patient engagement and activation.

b. Focus on developing and delivering patient education materials and programs that are informative, accessible, and tailored to individual patient needs to promote patient activation.

c. Invest in training healthcare professionals on the effective use of Virtual Twin Technology and patient education tools to maximize the benefits of these technologies.

V. Practical Recommendations:

a. Further exploration of the specific mechanisms and pathways through which Virtual Twin Technology and patient education influence patient engagement.

b. Longitudinal studies to track patient activation and engagement over time in response to Virtual Twin Technology and patient education interventions.

c. Investigate the impact of Virtual Twin Technology on other aspects of patient engagement, such as patient satisfaction, empowerment, and treatment adherence.

d. Conduct comparative studies to assess the effectiveness of Virtual Twin Technology-based interventions compared to traditional healthcare approaches.

The regression analysis provides valuable insights into the relationship between Virtual Twin Technology usage, patient education applications, and patient activation in healthcare. The results suggest that these factors play a crucial role in improving patient engagement and involvement in healthcare decision-making processes. However, as with any research study, the results should be interpreted in the context of the specific study's limitations and should be validated and applied carefully in real-world healthcare settings.

4.4.1.2 The regression analysis for the dependent variable "Patient Satisfaction".

Summary of the Interpretation of the Statistical Output for Patient Satisfaction:

I. Regression Analysis Results:

a. **Multiple R Value:** The multiple R value of 0.9256 indicates a strong positive correlation between predictor variables (Frequency of Virtual Twin Technology Usage, Diagnosis Application, Treatment Planning Application, Monitoring Application, and Patient Education Application) and patient satisfaction.

b. **R-Squared Value:** Approximately 85.68% of the variance in patient satisfaction is explained by the predictor variables. This suggests a substantial influence of these variables on patient satisfaction.

c. **Adjusted R-Squared Value:** The adjusted R-squared value of 0.8547, slightly lower than R-squared, still indicates a significant proportion of variance in patient satisfaction explained by the predictor variables.

d. **ANOVA:** The extremely low p-value (4.9055E-144) in the ANOVA table reinforces the statistical significance of the regression model, indicating that the relationship between predictor variables and patient satisfaction is not due to chance.

e. **Coefficients:**

    i. **Frequency of Virtual Twin Technology Usage:** Significant positive impact on patient satisfaction.

    ii. **Diagnosis, Treatment Planning, Monitoring Applications:** Not statistically significant predictors.

    iii. **Patient Education Application:** Significant positive impact on patient satisfaction.

II. Practical Implications:

a. The model explains approximately 85.68% of the variance in patient satisfaction, making it a valuable tool for healthcare organizations to enhance patient satisfaction levels.
b. The frequency of using Virtual Twin Technology and effective patient education applications significantly influences patient satisfaction.
c. Diagnosis, treatment-planning, and monitoring applications may not be strong predictors of patient satisfaction in this study's context.

III. Limitations of the Study:

a. Generalizations to other populations or settings should be made cautiously.
b. Further research and validation studies may be necessary to confirm the robustness and generalizability of these findings.

IV. Practical Recommendations:

a. Incorporating Virtual Twin Technology and effective patient education tools can lead to higher levels of patient activation and satisfaction.
b. Healthcare providers can improve patient engagement, involvement in their care, and overall satisfaction by leveraging these tools.
c. Implementing diagnosis, treatment planning, and monitoring applications alone may not be enough to significantly impact patient activation and satisfaction.

Overall Implications:

The findings suggest practical implications for healthcare organizations to enhance patient satisfaction by focusing on the frequency of virtual twin technology usage and effective patient education applications. These insights can inform strategic decisions in healthcare settings to improve patient engagement and overall satisfaction.

4.4.1.3 The regression analysis for the dependent variable "Patient Involvement in Decision-Making"

Summary of the Interpretation of the Statistical Output for Patient Involvement in Decision-Making:

I. **Regression Analysis Results:**

   a. **Multiple R Value:** The multiple R value of 0.8553 indicates a strong positive correlation between predictor variables and "Patient Involvement in Decision-Making," suggesting a significant relationship.

   b. **R-Squared Value:** Approximately 73.15% of the variance in patient involvement in decision-making can be explained by the predictor variables. The model accounts for a substantial proportion of the variability in patient involvement.

   c. **Adjusted R-Squared Value:** The adjusted R-squared value (0.7276) is close to R-squared, suggesting that the inclusion of predictor variables has not led to overfitting, and the model's explanatory power remains high.

   d. **ANOVA**: The ANOVA table shows a highly significant regression model ($p < 0.001$) with 5 degrees of freedom, indicating a good fit of the model to the data.

II. **Practical Implications:**

a. The model explains approximately 73.15% of the variance in patient involvement, emphasizing its value in predicting and understanding factors influencing patient participation in decision-making.

b. "Frequency of Virtual Twin Technology Usage" significantly and positively impacts patient involvement in decision-making.

c. Diagnosis, treatment planning, monitoring applications, and patient education application do not show statistically significant impacts on patient involvement in decision-making.

III. **Limitations of the Study:**

a. Generalizations to other populations or settings should be made cautiously.

b. The study's findings are specific to the context of the research, and further research may be needed to validate these results in different healthcare settings.

IV. **Practical Recommendations:**

a. Healthcare providers can focus on leveraging Virtual Twin Technology to enhance patient involvement in decision-making.

b. The study did not find significant impacts of diagnosis, treatment planning, monitoring applications, and patient education application on patient involvement. Therefore, additional strategies may be needed to improve patient participation in decision-making.

Overall Implications:

The findings suggest that Virtual Twin Technology plays a significant role in promoting patient involvement in decision-making. This information can guide healthcare providers and policymakers in developing strategies that leverage technology to enhance patient-centered care and improve patient outcomes. However, the study emphasizes the need for a nuanced approach, considering that not all applications examined had a significant impact. Context-specific considerations and further research can contribute to refining strategies for promoting patient involvement in decision-making.

4.4.2 Effects of virtual twin technology on clinical decision-making Processes

Summary of the Interpretation of the Statistical Output for Effects of virtual twin technology on clinical **decision-making Processes.**

I. **Regression Analysis Results:**

a. **Multiple R Value**: The multiple R value of 0.9158 indicates a strong positive correlation between predictor variables and the dependent variable, "Effects on Decision-Making," suggesting a significant relationship.

b. **R-Squared Value**: Approximately 83.87% of the variance in effects on decision-making can be explained by the predictor variables. The model accounts for a substantial proportion of the variability in decision-making effects.

c. **Adjusted R-Squared Value**: The adjusted R-squared value of 0.8373, slightly lower than the R-squared, reflects a more realistic estimate of the variance explained by the model.

d. **ANOVA**: The ANOVA table shows a highly significant regression model ($p < 0.001$) with 3 degrees of freedom, indicating a good fit of the model to the data.

II. **Practical Implications:**

a. The model explains approximately 83.87% of the variance in effects on decision-making, emphasizing its value in predicting and understanding factors influencing decision-making effects.
b. "Role in Clinical Decision Satisfaction" and "Role in Clinical Decision Involvement" have significant positive impacts on effects on decision-making.
c. "Role in Clinical Decision Activation" does not have a statistically significant effect on effects on decision-making in this analysis.

III. Limitations of the Study:

a. Generalizations to other populations or settings should be made cautiously.
b. The study's findings are specific to the context of the research, and further research may be needed to validate these results in different healthcare settings.

IV. Practical Recommendations:

a. Healthcare providers can focus on enhancing the satisfaction and involvement of clinicians in clinical decision-making processes to positively impact decision-making effects.
b. The study did not find a significant impact of the role in clinical decision activation, suggesting that attention should be directed towards other aspects for improving decision-making effects.

Overall Implications:

The regression analysis indicates that the role in clinical decision satisfaction and involvement significantly influences the effects on decision-making. However, the role in clinical decision activation did not show a statistically significant effect in this analysis.

This information can guide healthcare providers in understanding the factors that contribute to decision-making effects, allowing for targeted strategies to enhance decision-making processes. As with any statistical analysis, considering the context and limitations of the study is crucial when interpreting and applying the results in real-world settings.

CHAPTER V:

DISCUSSION

5.1 Discussion of Results

This thesis explores the impact of virtual Twin Technology and patient education on patient engagement and satisfaction in healthcare. The findings align with previous research on the potential benefits of Virtual Twin Technology in improving patient experiences and outcomes. The study confirms that Virtual Twin Technology usage frequency and patient education applications positively influence patient activation, with patients who utilized Virtual Twin Technology more frequently and had access to effective patient education programs demonstrating higher levels of activation in managing their health. The study's theoretical implications support patient engagement theories and the principles of patient-centered care and shared decision-making. From a practical perspective, the study highlights the significance of integrating Virtual Twin Technology and effective patient education strategies into healthcare practice to enhance patient activation and satisfaction. However, the generalizability of the findings to different healthcare settings and patient populations should be approached cautiously. Future research could explore the long-term effects of Virtual Twin Technology and patient education on patient activation, satisfaction, and other patient-centered outcomes. Investigating the mechanisms through which Virtual Twin Technology positively influences patient activation would provide additional insights into patient engagement in healthcare.This thesis contributes to the understanding of patient engagement in healthcare and the impact of Virtual Twin Technology on patient activation and satisfaction. By prioritizing patient engagement and integrating Virtual Twin Technology and effective patient education strategies, healthcare organizations can enhance patient satisfaction and overall healthcare quality. Healthcare professionals should invest in the development and implementation of Virtual Twin Technology platforms that cater to patients' unique needs and preferences, providing relevant and timely health information to patients. Tailored and informative patient education can empower patients with the knowledge and skills needed to actively participate in their healthcare decisions.

To further advance patient-centered care and optimize the use of Virtual Twin Technology in healthcare practice, future research should explore the long-term effects of Virtual Twin Technology usage and patient education on patient activation, satisfaction, and other patient-centered outcomes. Comparative effectiveness research can also compare the impact of different Virtual Twin Technology-based interventions and patient education approaches to guide decision-making in healthcare settings. Furthermore, future research should address the study's limitations, such as the reliance on self-reported data and the cross-sectional design. Using longitudinal designs and incorporating objective measures of patient activation and satisfaction can enhance the robustness of future studies. Ethical frameworks and guidelines for the responsible use of Virtual Twin Technology in healthcare should also be developed, ensuring patient data protection, confidentiality, and informed consent are essential aspects of implementing Virtual Twin Technology in a responsible and ethical manner.

This study investigates the impact of Virtual Twin Technology and patient education on patient activation and satisfaction in healthcare. The study confirms that patients who frequently use Virtual Twin Technology and receive effective patient education are more activated and satisfied with their healthcare experiences. By prioritizing patient-centered care, integrating Virtual Twin Technology, and delivering effective patient education, healthcare providers can foster patient activation, autonomy, and satisfaction, ultimately leading to improved patient outcomes, increased patient loyalty, and better overall quality of care. As technology continues to evolve, ongoing research is crucial to ensure that patient empowerment remains a central focus in healthcare practice and policy. By embracing the potential of Virtual Twin Technology and patient education, healthcare providers and policymakers can empower patients to actively manage their health, leading to improved healthcare outcomes and enhanced patient satisfaction.

The research questions/objectives were to examine the relationship between Virtual Twin Technology usage and patient involvement in decision-making, explore the impact of different Virtual Twin Technology applications (diagnosis, treatment planning, monitoring, and patient education), compare the findings with previous studies to identify consistencies and disparities, discuss the theoretical and practical implications of the research findings, assess the generalizability of the results across diverse healthcare contexts, identify unanswered questions and suggest directions for future research, and contribute to the existing knowledge on the role of Virtual Twin Technology in healthcare and patient engagement. The regression analysis revealed a strong positive relationship between Virtual Twin Technology usage and patient involvement in decision-making. The adjusted R-squared value of 0.728 suggested that the model's explanatory power remained high even after adjusting for model complexity. Among the predictor variables, the frequency of Virtual Twin Technology usage had a significant positive impact on patient involvement in decision-making, with a coefficient of 22.82. However, the other Virtual Twin Technology applications, including diagnosis, treatment planning, monitoring, and patient education, did not show statistically significant impacts on patient involvement in decision-making.

The research hypotheses were partially supported by the findings, with the hypothesis that Virtual Twin Technology usage would positively influence patient involvement in decision-making being supported. However, the hypotheses related to other Virtual Twin Technology applications (diagnosis, treatment planning, monitoring, and patient education) were not supported. The theoretical implications of the study underscore the importance of patient-centered care and patient engagement theories in shaping healthcare practices. The findings align with the principles of patient-centered care and shared decision-making, highlighting Virtual Twin Technology's potential to empower patients and promote active participation in their healthcare decisions. The practical implications of this research are significant for healthcare providers and organizations, emphasizing the importance of promoting Virtual Twin Technology usage to enhance patient involvement in decision-making processes. By leveraging Virtual Twin Technology and providing patients with access to their virtual twin representations, healthcare providers can foster patient engagement, improve treatment plan adherence, and ultimately achieve better patient outcomes. Healthcare organizations should focus on the frequency of Virtual Twin Technology usage to maximize patient engagement.

Generalizability of the results should be approached with caution, as the study was conducted in a specific healthcare setting and the findings may not fully represent other healthcare contexts or patient populations. Unanswered questions and future research opportunities remain, such as the mechanisms through which Virtual Twin Technology influences patient involvement and the potential mediating factors linking technology usage and patient engagement. This study explores the role of Virtual Twin Technology (VTT) in healthcare and patient engagement, revealing a strong positive relationship between VTT usage and patient involvement in decision-making. The frequency of technology usage significantly influenced patient involvement, adding to the existing body of evidence supporting the positive impact of VTT on patient outcomes and emphasizing the importance of patient-centered care and shared decision-making. The study adds to the existing body of evidence supporting the positive impact of VTT on patient outcomes and emphasizes the importance of patient-centered care and shared decision-making. Further research is needed to validate and extend these findings to diverse healthcare settings and patient populations.

Recommendations for enhancing the implementation and impact of VTT in healthcare include promoting virtual twin technology adoption, encouraging patient education, personalizing virtual twin representations, evaluating patient outcomes, addressing data privacy and security concerns, and exploring integration with decision support systems. However, it is essential to acknowledge the limitations of this study, such as the specific healthcare setting with a limited sample size, which may limit the generalizability of the findings to other healthcare contexts. Longitudinal studies tracking the effects of VTT over time can offer more robust evidence of its sustained impact on decision-making processes. Future research directions include longitudinal studies tracking patient involvement and outcomes over time, comparative studies evaluating the effectiveness of VTT against traditional care models, investigating potential mediating factors between VTT Technology usage and patient involvement, and qualitative research capturing patient perspectives on VTT usage. This study has shed light on the significant impact of VTT on patient engagement in healthcare, emphasizing the importance of leveraging technology to promote patient-centered care and shared decision-making. By embracing VTT and addressing its limitations, healthcare organizations can create a patient-centric healthcare ecosystem that fosters active patient participation and informed decision-making, ultimately leading to improved healthcare experiences and outcomes. This study explores the impact of Virtual Twin Technology on patient involvement in decision-making in healthcare, highlighting the need for healthcare providers to embrace this technology to improve patient outcomes. The findings demonstrate a strong positive relationship between VTT usage and patient engagement, emphasizing the need for healthcare providers to embrace this technology to create a patient-centric healthcare ecosystem that fosters active patient participation and informed decision-making, ultimately leading to improved healthcare experiences and outcomes.

Future research directions include conducting longitudinal studies that track patient involvement and outcomes over extended periods, conducting comparative studies that evaluate the effectiveness of Virtual Twin Technology against traditional care models, investigating potential mediating factors between Virtual Twin Technology usage and patient involvement, capturing patient perspectives on Virtual Twin Technology usage, identifying factors influencing healthcare professionals' role satisfaction with Virtual Twin Technology, investigating the impact on specific medical conditions or patient populations, and assessing the impact of VTT on different age groups. This study contributes to existing knowledge on the role of Virtual Twin Technology in healthcare and patient engagement, by exploring the impact of VTT on patient involvement in decision-making and healthcare professionals' role satisfaction. It underscores the importance of involving healthcare professionals and ensuring their satisfaction with technology to maximize its benefits in patient care. Furthermore, the research adds to the growing body of evidence supporting the positive influence of Virtual Twin Technology on healthcare outcomes and patient engagement by examining the factors that drive successful VTT integration. this thesis highlights the significance of leveraging technology to promote patient-centered care and shared decision-making in healthcare. By examining the factors that drive successful VTT integration, this study bridges the gap between technology adoption and patient-centered care, ultimately contributing to improved healthcare outcomes. Future research should validate and extend these findings to diverse healthcare settings and patient populations, focusing on the transformative power of Virtual Twin Technology and addressing its limitations to create a patient-centric healthcare ecosystem that fosters active patient participation and informed decision-making.

Virtual Twin Technology (VTT) has the potential to revolutionize patient engagement and clinical decision-making in healthcare. The study's results demonstrate a significant positive relationship between VTT usage and patient involvement in decision-making, emphasizing the importance of involving healthcare professionals and ensuring their satisfaction to maximize VTT's impact on decision-making processes. By embracing VTT and addressing its limitations, healthcare organizations can foster a patient-centric ecosystem that promotes active patient participation and informed decision-making. This transformative technology has the potential to reshape healthcare delivery and usher in a new era of patient-centered care. Future research and practice should strive to maximize its benefits while ensuring ethical and responsible use in healthcare decision-making processes. By leveraging the transformative power of VTT and addressing its limitations, healthcare providers can optimize patient engagement and improve the quality of care delivery. As Virtual Twin Technology continues to evolve and find applications in various healthcare contexts, it is essential for researchers, healthcare providers, and policymakers to collaborate in exploring its full potential. By embracing the transformative power of VTT, healthcare systems can move towards patient-centered care models, where patients are active participants in their healthcare decisions.

The successful integration of Virtual Twin Technology into healthcare practices requires a comprehensive approach that considers technical, ethical, and human aspects. By promoting technology adoption, educating patients and healthcare professionals, ensuring data privacy, and fostering collaboration between stakeholders, healthcare organizations can harness the power of VTT to deliver personalized, efficient, and patient-centric care. The study made significant contributions to the knowledge on VTT's role in healthcare and patient engagement. By embracing VTT and addressing its limitations, healthcare organizations can foster a patient-centric ecosystem that promotes active patient participation and informed decision-making, ultimately improving healthcare experiences and outcomes.

I. Promote Virtual Twin Technology Adoption: Healthcare organizations should actively promote the adoption of VTT in clinical practice by providing training programs and workshops to healthcare professionals.

II. Encourage Patient Education: To maximize the impact of VTT, healthcare providers should educate patients about the benefits of using virtual twins to track their health, understand treatment plans, and actively participate in their care decisions.

III. Personalize Virtual Twin Representations: Tailoring virtual twin representations to individual patient needs can enhance patient engagement.

IV. Evaluate Patient Outcomes: Continuous evaluation of patient outcomes and experiences related to VTT usage is essential. Healthcare organizations should monitor patient satisfaction, treatment plan adherence, and health outcomes to assess the technology's effectiveness and identify areas for improvement.

V. Address Data Privacy and Security Concerns: To build patient trust and ensure ethical use of VTT, robust data privacy and security measures should be implemented.

Explore Integration with Decision Support Systems: Integrating VTT with decision support systems can further enhance patient involvement in decision-making, providing personalized treatment recommendations, empowering patients to make informed choices about their care.

Study explores the impact of Virtual Twin Technology (VTT) on patient involvement in decision-making in healthcare, highlighting the need for healthcare providers to embrace this technology to improve patient outcomes. The findings demonstrate a strong positive relationship between VTT usage and patient engagement, emphasizing the need for healthcare providers to embrace this technology to foster a patient-centric healthcare ecosystem that fosters active patient participation and informed decision-making. Future research directions include conducting longitudinal studies that track patient involvement and outcomes over extended periods, conducting comparative studies that evaluate the effectiveness of VTT against traditional care models, investigating potential mediating factors, gathering patient perspectives on VTT usage, examining factors influencing healthcare professionals' role satisfaction with VTT, assessing the impact on specific medical conditions or patient populations, and assessing age-specific considerations. The study contributes to existing knowledge on the role of Virtual Twin Technology in healthcare and patient engagement by exploring the significant positive relationship between VTT usage and patient involvement in decision-making. It highlights the significance of involving healthcare professionals and ensuring their satisfaction to maximize its benefits in patient care. By examining the factors driving successful VTT integration, this study bridges the gap between technology adoption and patient-centered care, ultimately contributing to improved healthcare outcomes. In the pursuit of implementing Virtual Twin Technology effectively, collaboration and interdisciplinary efforts play a vital role. Researchers, healthcare professionals, technologists, policymakers, and patients must work together to refine the technology's applications, address ethical concerns, and optimize its impact on patient outcomes. This multidimensional approach ensures that Virtual Twin Technology aligns with the principles of patient-centered care and shared decision-making, leading to enhanced patient experiences and better healthcare outcomes.

A proactive approach to addressing potential barriers and challenges is essential for the successful integration of Virtual Twin Technology into healthcare practices. Key challenges may include resistance to technology adoption among healthcare professionals, data privacy concerns, technological infrastructure requirements, and patient engagement barriers. Addressing these challenges through targeted interventions, education, and policy support will facilitate the smooth integration of Virtual Twin Technology into healthcare practices. The future of Virtual Twin Technology lies in its continuous evolution and adaptation. As new advancements in technology emerge, such as artificial intelligence, machine learning, and augmented reality, incorporating these innovations into Virtual Twin applications can further enhance patient engagement and decision-making processes. For instance, the integration of AI-powered decision support systems with Virtual Twin Technology can provide real-time personalized treatment recommendations, making patient-centered care even more efficient and effective. Ethical considerations remain at the forefront of Virtual Twin Technology adoption. Healthcare providers and technology developers must prioritize patient data privacy and informed consent, implement robust data protection measures, and ensure patients have control over their data to foster trust and confidence in using Virtual Twin Technology in healthcare settings. Finally, research efforts should continue to explore the impact of Virtual Twin Technology on specific medical conditions, diverse patient populations, and healthcare systems worldwide.

The regression analysis findings provide valuable insights into the impact of virtual twin technology on patient engagement, clinical decision-making processes, and healthcare outcomes. These findings align with previous research that highlights the positive influence of virtual twin technology in healthcare. Let's contrast and compare these findings with relevant academic papers to strengthen the validity of the study.

5.2 Discussion of Research Question One

I. **Patient Engagement:**The results from the regression analysis suggest that virtual twin technology positively impacts patient engagement in healthcare. Similar findings have been reported in other academic papers. For example, (Anderson et al.2022) conducted a study at the University of California, San Francisco, which found that patients using virtual twins to track their health showed better adherence to treatment plans, improved clinical outcomes, and higher satisfaction with care. This is in line with the current study's findings, where the frequency of virtual twin technology usage positively correlated with patient activation and satisfaction. Furthermore, the study by (Rizzo et al. 2021) from the Mayo Clinic also reported that patients who used a virtual twin to track their heart health were more likely to participate in cardiac rehabilitation programs and had better long-term outcomes. The current study's findings support this notion of virtual twin technology facilitating remote monitoring and personalized care delivery. To strengthen the validity of the study, the current research could cite and discuss similar findings from (Anderson et al. 2022) and (Rizzo et al. 2021) to show consistency in the literature regarding the impact of virtual twin technology on patient engagement.

5.3 Discussion of Research Question Two

II. **Clinical Decision-Making:** The regression analysis results suggest that virtual twin technology has a significant impact on patient satisfaction and involvement in decision-making. However, specific applications of virtual twin technology, such as diagnosis, treatment planning, and monitoring, did not show significant impacts in this study. To contrast these findings, the study could cite research from other academic papers that explore the role of virtual twin technology in clinical decision-making with more emphasis on specific applications. For instance, a study by (Smith et al. 2020) might be relevant, which investigated the use of virtual twins in surgical planning and decision-making. This study could provide additional insights into the potential impacts of virtual twins in specific medical fields. By discussing these contrasting findings from other studies, the current research can further validate its own findings and provide a more comprehensive picture of the role of virtual twin technology in clinical decision-making processes.

III. **Healthcare Outcomes:** The regression analysis results indicate that the frequency of virtual twin technology usage significantly impacts healthcare outcomes. This finding aligns with the literature on virtual twin technology's potential to improve healthcare outcomes through predictive modeling and proactive interventions. To enhance the validity of the study, the researchers could cite more recent academic papers that corroborate these findings. For instance, a review article by (Wang et al. 2023) might be relevant, which discusses the impact of digital twins on healthcare outcomes and patient safety. This review could provide additional evidence to support the current study's findings on the contribution of virtual twin technology to improving healthcare outcomes. By citing and discussing similar findings from other research, the current study can strengthen the argument for the positive impact of virtual twin technology on healthcare outcomes.

While the regression analysis provides valuable insights, comparing and contrasting the findings with relevant academic papers will enhance the validity and robustness of the study. By acknowledging similar findings and discussing any discrepancies with existing literature, the current research can establish a strong foundation for the potential impact of virtual twin technology in healthcare.

Additional suggestions to enhance the discussion and validity of the study:

I. **Meta-Analyses and Systematic Reviews:** To further strengthen the validity of the study, the researchers could also consider citing meta-analyses or systematic reviews that have synthesized findings from multiple studies on the impact of virtual twin technology in healthcare. Meta-analyses provide a comprehensive and quantitative approach to analyzing the collective evidence from various studies, thus offering more robust conclusions. For instance, a meta-analysis by (Li et al. 2022) investigated the effects of virtual twin technology on patient engagement, clinical decision-making, and healthcare outcomes. This meta-analysis could be a valuable resource for the current study to support and validate its own findings.

II. **Generalizability:** Additionally, to address any potential limitations related to the specific sample of healthcare professionals used in the study, the researchers could compare their results with findings from studies that involved different healthcare settings or diverse populations. This would help to understand the generalizability of the current study's findings and provide a more comprehensive perspective on the impact of virtual twin technology across various healthcare contexts.

III. **Practical Implications:** Furthermore, to enhance the discussion on the implications of the study's findings, the researchers could explore practical implications and recommendations for healthcare organizations and policymakers. For instance, they could discuss strategies for integrating virtual twin technology into existing healthcare systems, addressing potential barriers to adoption, and ensuring patient data privacy and security.

IV. **Addressing Ethical Considerations:** It is essential to address potential ethical considerations and challenges associated with virtual twin technology. For instance, the researchers could discuss how data privacy and security concerns are managed, how informed consent is obtained from patients for using virtual twin technology, and how potential biases in the data are addressed to ensure fair and equitable healthcare outcomes.

V. **Longitudinal Studies:** While the study's regression analysis provides valuable insights into the associations between virtual twin technology and healthcare outcomes, future research could benefit from conducting longitudinal studies. Longitudinal studies would allow for the examination of the long-term impact of virtual twin technology implementation, providing evidence on the sustainability of the technology's benefits over time.

VI. **International Perspectives:** The study's findings could be strengthened by incorporating international perspectives on the use of virtual twin technology in healthcare. By examining how different healthcare systems and cultural contexts adopt and implement the technology, the study can offer valuable insights into the global implications of virtual twin technology.

VII. **Comparison with Other Digital Health Technologies:** To provide a comprehensive understanding of virtual twin technology's unique contributions, the researchers could compare its impact with other digital health technologies that aim to improve patient engagement, clinical decision-making, and healthcare outcomes. This could include technologies like telemedicine, wearable devices, remote monitoring systems, and artificial intelligence applications. By contrasting virtual twin technology with other innovations, the study can highlight its specific advantages and potential synergies with existing digital health solutions.

VIII. **Future Directions and Research Opportunities:** Concluding the discussion with future directions and research opportunities can highlight the potential areas for further investigation and innovation in the field of virtual twin technology. This could include exploring the use of virtual twins in specific medical specialties, investigating its integration with emerging technologies like blockchain or Internet of Things (IoT), and studying its long-term impact on healthcare system transformation.

IX. **Replication and External Validation:** To strengthen the study's validity, the researchers could encourage replication and external validation of their findings by other research teams in different healthcare settings. This collaborative approach would contribute to building a robust body of evidence on the impact of virtual twin technology in healthcare.

X. **Limitations and Generalizability:** The discussion should acknowledge any limitations of the study and consider their implications for the generalizability of the findings. Addressing potential biases, sample size limitations, or specific contextual factors will provide a balanced view of the study's scope and applicability.

XI. **Policy Implications:** Finally, the discussion could highlight the policy implications of the study's findings. Policymakers and healthcare administrators can benefit from understanding how virtual twin technology aligns with broader healthcare policy goals and how it can be integrated into healthcare reform initiatives to improve patient outcomes and system efficiency.

By incorporating these additional elements into the study's discussion, the researchers can present a comprehensive and well-rounded analysis of the impact of virtual twin technology in healthcare. The discussion will contribute valuable insights to the academic community, healthcare practitioners, and policymakers, ultimately advancing the adoption and integration of virtual twin technology for better patient outcomes and improved healthcare delivery.

CHAPTER VI:

SUMMARY, IMPLICATIONS, AND RECOMMENDATIONS

6.1 Summary

The regression analysis in this study delved into the influence of Virtual Twin Technology (VTT) on patient engagement, clinical decision-making, and healthcare outcomes. It uncovered several significant associations, highlighting the positive effects of VTT on patient activation, satisfaction, and overall healthcare results. Although specific applications of VTT in diagnosis and treatment planning exhibited non-significant impacts, the broader implications suggested the transformative potential of VTT in healthcare. The study contributes by offering empirical evidence and emphasizing the necessity for further exploration to comprehensively grasp VTT's role in shaping the healthcare landscape.

Not only that this study conducted an in-depth regression analysis with the primary objective of examining how Virtual Twin Technology (VTT) influences key aspects of healthcare, specifically patient engagement, clinical decision-making, and overall healthcare outcomes. The research findings unveiled compelling associations that shed light on the positive impacts of VTT on critical elements of the healthcare process.

In terms of patient engagement, the study identified a significant positive correlation between the use of VTT and patient activation levels. This implies that as the frequency of utilizing VTT increased, patients exhibited higher levels of activation, emphasizing the technology's role in empowering individuals to take an active role in managing their health. Furthermore, the study revealed a noteworthy positive impact on patient satisfaction, indicating that the integration of VTT contributes to heightened contentment among patients regarding their healthcare experiences.

Despite these positive trends, the analysis also explored specific applications of VTT, such as its role in diagnosis and treatment planning. Surprisingly, these particular applications did not show a statistically significant impact in the current analysis. This suggests that while certain aspects of VTT may not be as influential in specific medical processes, the overall implications of its integration into healthcare are still transformative and positive.

The study's contributions go beyond these findings, serving as empirical evidence of the tangible benefits of VTT in healthcare. It serves as a foundational piece, emphasizing the need for continuous exploration and understanding of VTT's multifaceted role in shaping the future of healthcare delivery. By offering robust evidence, the study provides a platform for further research and discourse, urging the scientific community to delve deeper into the intricacies of VTT and its broader implications.

In essence, the study's detailed regression analysis underscores the nuanced nature of VTT's impact on healthcare. It not only highlights the positive associations in patient engagement and satisfaction but also acknowledges the complexity of specific applications. The study, therefore, serves as a catalyst for ongoing investigations, urging researchers, healthcare practitioners, and policymakers to collaboratively explore and harness the transformative potential of Virtual Twin Technology in healthcare delivery.

6.2 Implications

The implications of the study are far-reaching, offering insights that span multiple dimensions within the healthcare landscape.

6.2.1 Enhanced Patient Engagement:

I. The positive associations between Virtual Twin Technology (VTT) usage frequency and patient activation and satisfaction underscore its potential to significantly enhance patient engagement.

II. Improved patient engagement can lead to better comprehension of health conditions, informed decision-making, and enhanced self-management skills, thereby contributing to heightened healthcare quality and improved patient outcomes.

6.2.2 Patient-Centered Care and Shared Decision-Making:

I. The study's findings emphasize that VTT has a substantial impact on patient satisfaction and involvement in decision-making processes.

II. This underscores the pivotal role of patient-centered care and shared decision-making facilitated by VTT. Healthcare organizations can leverage these insights to tailor their approaches, thereby promoting better adherence to treatment plans and overall patient satisfaction.

6.2.3 Improved Healthcare Outcomes:

I. The positive impact of VTT usage frequency on healthcare outcomes suggests a transformative potential in terms of proactive interventions and personalized care plans.

II. By integrating patient data and employing advanced analytics, VTT enables healthcare providers to deliver timely and tailored interventions, resulting in improved patient outcomes, a decrease in readmissions, and overall enhanced healthcare efficiency.

6.2.4 Strategic Healthcare Planning:

I. Healthcare organizations can strategically incorporate VTT into their planning processes to enhance patient engagement, satisfaction, and outcomes.

II. Understanding the positive correlations highlighted in the study allows for the development of targeted strategies aimed at maximizing the benefits of VTT, ultimately leading to more patient-centric and effective healthcare delivery.

6.2.5 Technological Integration and Training:

I. The study's implications suggest that healthcare providers need to invest in integrating VTT seamlessly into their existing systems.

II. Additionally, training programs for healthcare professionals on effectively utilizing VTT can be crucial in realizing its potential benefits, ensuring that the technology is harnessed to its full capacity.

6.2.6 Policy Considerations:

I. Policymakers can consider the study's findings in shaping regulations and guidelines that facilitate the responsible and widespread adoption of VTT.

II. Crafting policies that prioritize patient-centered care, shared decision-making, and the integration of innovative technologies like VTT can contribute to a more responsive and efficient healthcare system.

In conclusion, the study's implications extend beyond the immediate findings, offering a roadmap for healthcare organizations and policymakers to embrace and leverage the potential of Virtual Twin Technology. By focusing on enhanced patient engagement, patient-centered care, and improved healthcare outcomes, stakeholders in the healthcare ecosystem can collectively work towards a future that is both technologically advanced and inherently patient-centric.

6.3 Recommendations for Future Research

I. **Meta-Analyses and Systematic Reviews:**

   a. Incorporate references to relevant meta-analyses or systematic reviews that have synthesized findings on the impact of VTT in healthcare. This would provide a more comprehensive and quantitative approach to analyzing collective evidence.

   b. For example, citing a meta-analysis by Li et al. (2022) that investigated the effects of VTT on patient engagement, clinical decision-making, and healthcare outcomes could strengthen the study's validity.

II. **Generalizability:**

   a. Compare the study's results with findings from studies conducted in different healthcare settings or with diverse populations. This would help in understanding the generalizability of the study's findings and provide a more comprehensive perspective on the impact of VTT across various healthcare contexts.

III. **Practical Implications:**

   a. Explore practical implications and recommendations for healthcare organizations and policymakers. This could involve strategies for integrating VTT into existing healthcare systems, addressing potential barriers to adoption, and ensuring patient data privacy and security.

IV. **Ethical Considerations:**

   a. Address potential ethical considerations and challenges associated with VTT. Discuss how data privacy and security concerns are managed, how informed consent is obtained from patients for using VTT, and how potential biases in the data are addressed to ensure fair and equitable healthcare outcomes.

V. **Longitudinal Studies:**

a. While the study's regression analysis provides valuable insights, future research could benefit from conducting longitudinal studies. This would allow for the examination of the long-term impact of VTT implementation, providing evidence on the sustainability of the technology's benefits over time.

VI. **International Perspectives:**

a. Strengthen the study's findings by incorporating international perspectives on the use of VTT in healthcare. Examine how different healthcare systems and cultural contexts adopt and implement the technology to offer valuable insights into the global implications of VTT.

VII. **Comparison with Other Digital Health Technologies:**

a. Provide a comprehensive understanding of VTT's unique contributions by comparing its impact with other digital health technologies. This could include technologies like telemedicine, wearable devices, remote monitoring systems, and artificial intelligence applications. Contrasting VTT with other innovations can highlight its specific advantages and potential synergies with existing digital health solutions.

VIII. **Future Directions and Research Opportunities:**

a. Conclude the discussion with future directions and research opportunities in the field of VTT. Explore potential areas for further investigation and innovation, such as the use of VTT in specific medical specialties, its integration with emerging technologies like blockchain or Internet of

Things (IoT), and its long-term impact on healthcare system transformation.

IX. **Replication and External Validation:**

a. Encourage replication and external validation of the study's findings by other research teams in different healthcare settings. This collaborative approach would contribute to building a robust body of evidence on the impact of VTT in healthcare.

X. **Limitations and Generalizability:**

a. The discussion should acknowledge any limitations of the study and consider their implications for the generalizability of the findings. Addressing potential biases, sample size limitations, or specific contextual factors will provide a balanced view of the study's scope and applicability.

XI. **Policy Implications:**

a. Highlight the policy implications of the study's findings. Provide insights for policymakers and healthcare administrators on how VTT aligns with broader healthcare policy goals and how it can be integrated into healthcare reform initiatives to improve patient outcomes and system efficiency.

6.4 Conclusion

In concluding the regression analysis on the impact of Virtual Twin Technology (VTT) in healthcare, this study provides valuable insights that contribute significantly to the ongoing discourse on the transformative potential of VTT. The empirical evidence gathered through rigorous analysis aligns with existing literature and reinforces the positive associations between VTT usage and key healthcare parameters.

I. **Empirical Evidence and Positive Associations:**

   a. The study stands as a robust addition to the body of evidence affirming the positive influence of VTT in healthcare. Through meticulous regression analysis, the research establishes concrete associations between VTT usage and crucial aspects of healthcare, such as patient engagement, clinical decision-making, and overall healthcare outcomes.

   b. The empirical evidence presented reinforces the notion that VTT plays a pivotal role in positively influencing patient activation and satisfaction.

II. **Patient-Centric Impact:**

   a. A significant contribution of the study lies in highlighting the patient-centric impact of VTT, particularly in terms of patient engagement. By focusing on patient activation and satisfaction, the findings emphasize the potential of VTT to revolutionize how patients perceive and interact with their healthcare journey.

   b. The emphasis on patient-centric outcomes aligns with the broader shift towards personalized and patient-centered care in contemporary healthcare practices.

III. **Implications for Practice and Policy:**

   a. The discussion surrounding implications traverses practical, policy-oriented, and patient-centric considerations. This multi-faceted approach underscores the depth of the study's findings and their potential impact on diverse aspects of the healthcare ecosystem.

   b. Healthcare practitioners can leverage the insights to enhance patient experiences, while policymakers can utilize the evidence to shape regulations that foster responsible and widespread integration of VTT.

IV. **Acknowledgment of Limitations and Call for Further Research:**

a. The study maintains a transparent acknowledgment of its limitations, including the reliance on self-reported data and the need for more diverse samples. This humility in recognizing the study's constraints adds to its credibility and lays the foundation for future investigations to address these gaps.

b. The explicit call for further research underscores the dynamic nature of the field and the need for ongoing exploration to refine our understanding of VTT's role in healthcare.

V. **Roadmap for Future Research:**

a. The extensive recommendations for future research serve as a comprehensive roadmap for the academic community, healthcare practitioners, and policymakers. By delving into areas such as longitudinal studies, international perspectives, and comparisons with other digital health technologies, the study paves the way for a holistic understanding of VTT's potential.

b. Addressing ethical considerations, exploring implementation strategies, and encouraging replication by other research teams further enriches the research landscape and contributes to the robustness of evidence.

VI. **Integration of VTT into Healthcare Practices:**

a. The study's conclusion resonates with a resounding call for the integration of VTT into healthcare practices. This advocacy stems from the belief that VTT has the capacity to enhance patient outcomes, improve healthcare delivery, and contribute to the evolution of a more patient-centric and efficient healthcare system.

In summary, the regression analysis findings presented in this study not only substantiate the positive impact of VTT in healthcare but also set the stage for a nuanced understanding of its implications and future avenues of exploration. As the healthcare landscape continues to evolve, embracing technologies like VTT becomes not just a choice but a strategic imperative in shaping a healthcare future that is data-driven, patient-centered, and optimally efficient.

APPENDIX A

SURVEY COVER LETTER

[Recipient's Name]

[Recipient's Title or Affiliation]

[Recipient's Organization]

[Address]

Dear [Recipient's Name],

I hope this letter finds you well. My name is [Your Name], and I am a [Your Title or Role] currently working on my thesis at [Your University or Organization]. As a part of my research "Virtual Twin in Healthcare,".

I want to assure you that the following sample cover letter emphasizes the anonymity of the survey. Your participation in the actual survey is completely anonymous. Your responses will be treated with the utmost confidentiality, and no personally identifiable information will be shared or disclosed. The information gathered will be used solely for academic purposes and will contribute significantly to the depth and breadth of my thesis.

Your participation is entirely voluntary, and you may withdraw from the survey at any time without any consequences.

Thank you for considering my request, and I look forward to your participation.

Sincerely,

[Your Full Name]

[Your Title] [Your University or Organization]

[Your Contact Information]

APPENDIX B

VERBAL INFORMED CONSENT

Title: Virtual Twin in Healthcare - Research Study

Researcher: [Your Full Name]

Introduction: Thank you for considering participating in this research study. Before deciding whether to participate, it is important that you understand the purpose of the study, what will be expected of you, and any potential risks and benefits.

Purpose of the Study: The purpose of this research is to explore and understand the impact and potential applications of Virtual Twin technology in healthcare. We aim to gather insights on perceptions, experiences, and expectations related to this technology.

Procedures: You will be asked to participate in [describe the specific procedures involved in the study, such as interviews, surveys, or observations related to Virtual Twin technology in healthcare].

Confidentiality: Your participation in this study is entirely anonymous. Your personal information will not be shared, and all data will be kept confidential. No personally identifiable information will be disclosed in any reports or publications resulting from this research.

Voluntary Participation: Participation in this study is entirely voluntary. You may choose not to participate or may withdraw at any time without any consequences.

Benefits and Risks: There are no direct benefits or risks associated with participating in this study. Your input will contribute to the advancement of knowledge in the field of Virtual Twin technology in healthcare.

Contact Information: If you have any questions or concerns about the study, you may contact [Your Full Name] at [Your Email Address] or [Your Phone Number].

Consent: I have read and understood the information provided above. I have had the opportunity to ask questions, and my questions have been answered to my satisfaction. I voluntarily agree to participate in this study.

Participant's Name: ________________________
Participant's Signature: ________________________
Date: ________________________

APPENDIX C

INTERVIEW GUIDE

SURVEY

PERSONAL INFORMATION:

NAME EMPLOYEE ID DOMAIN

GENDER: Male Female EXPERIENCE:

Unit No. Street City State Zip Code

ADDRESS:

Prefer Not to show personal information

QUESTIONS:	RATING SCALE:
How often do you use virtual twin technology in your healthcare practice?	1=Rarely; 2=Sometimes; 3=Often; 4=Frequently; 5=Very Frequently
Have you used virtual twin technology for diagnosis purposes? how would you rate its effectiveness in aiding the diagnostic process?	0=Not Effective; 1=Highly Effective
In what ways have you utilized virtual twin technology for treatment planning? , how would you rate the contribution of virtual twin technology in developing comprehensive treatment plans?	0=No Contribution; 1=Significant Contribution
Have you integrated virtual twin technology into patient monitoring processes? , how would you rate the improvement in patient monitoring due to virtual twin technology?	0=No Improvement; 1=Significant Improvements
How do you incorporate virtual twin technology in patient education and engagement? how effective do you find virtual twin technology in improving patient understanding and involvement in their healthcare?	0=Not Effective; 1=Highly Effective
How do you perceive the level of patient activation in managing their healthcare? how would you rate the impact of virtual twin technology on patient activation?	1%=No Impact; 50%=Average Impact; 100%=Significant Impact
How satisfied are your patients with their healthcare experiences, including interactions with healthcare professionals and treatment outcomes? how much do you believe virtual twin technology has contributed to patient satisfaction?	1%=Not Satisfied; 50%=Satisfied; 100%=Very Satisfied
How involved do patients feel in the decision-making process regarding their treatment options? how would you rate the influence of virtual twin technology on patient involvement in decision-making?	1%=Not Influential; 50%=Somewhat Influential; 100%=Very Influential
How frequently are you involved in making clinical decisions in your current role?	1=Not Involved; 5= Somewhat involved; 10= Totally Involved
How satisfied are you with your current level of involvement in clinical decision-making? Please rate on a role in Clinical Decision Satisfaction.	1=Not Satisfied; 5=Satisfied; 10=Very Satisfied
How involved do you feel in the clinical decision-making processes?	1=Not Involved; 5=Somewhat involved; 10=Significantly Involved
How positively do you perceive the impact of virtual twin technology on clinical decision-making processes?	1= Disagree; 5= Somewhat Agree; 10= Agree
How strongly do you believe that virtual twin technology contributes to overall improvements in healthcare outcomes?	1%=Not Satisfied; 50%=Satisfied; 100%=Very Satisfied

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APPENDIX A:

FIRST APPENDIX TITLE [USE “CHAPTER TITLE” STYLE]

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